(374)

PRICE TEN SHILLINGS AND SIXPENCE

THE JOURNAL OF The Institution of Electrical Engineers

ORIGINALLY

The Society of Telegraph Engineers

FOUNDED 1871

INCORPORATED BY ROYAL CHARTER 1921

EDITED BY W. K. BRASHER, SECRETARY

SAVOY PLACE, VICTORIA EMBANKMENT, LONDON, W.C.2.

Telegrams: "VOLTAMPERE, PHONE, LONDON." Telephone: TEMPLE BAR 7676.

Vol. 85 DECEMBER, 1939 No. 516

CONTENTS.

(The Institution is not, as a body, responsible for the opinions expressed by individual authors or speakers.)

E. and F. N. SPON LIMITED, 57 HAYMARKET, LONDON, S.W.1.

CHEMICAL PUBLISHING COMPANY OF N.Y. INC., 148 LAFAYETTE STREET, NEW YORK.

The Institution of Electrical Engineers.

FOUNDED 1871

INCORPORATED BY ROYAL CHARTER 1921

PATRON: HIS MAJESTY KING GEORGE VI.

COUNCIL, 1939-1940.

President.

JOHNSTONE WRIGHT.

Past-Presidents.

COLONEL R. E. CROMPTON, C.B., F.R.S.
SIR JAMES SWINBURNE, BART., F.R.S.
CHARLES P. SPARKS, C.B.E.
ROGER T. SMITH.
J. S. HIGHFIELD.
F. GILL, O.B.E.
A. RUSSELL, M.A., D.Sc., LL.D., F.R.S.
W. B. WOODHOUSE.
W. H. ECCLES, D.Sc., F.R.S.
SIR ARCHIBALD PAGE.
LIEUT.-COL. K. EDGCUMBE, T.D.
COLONEL SIR THOMAS F. PURVES, O.B.E.
CLIFFORD C. PATERSON, O.B.E., D.Sc.
J. M. DONALDSON, M.C.
PROF. E. W. MARCHANT, D.Sc.
P. V. HUNTER, C.B.E.
PROF. W. M. THORNTON, O.B.E., D.Sc., D.Eng.
J. M. KENNEDY, O.B.E.
H. T. YOUNG.
SIR GEORGE LEE, O.B.E., M.C.
A. P. M. FLEMING, C.B.E., D.Eng., M.Sc.

Vice-Presidents.

COL. A. S. ANGWIN, D.S.O., M.C.
SIR NOEL ASHBRIDGE, B.Sc. (Eng.).
J. R. BEARD, M.Sc.
PROF. C. L. FORTESCUE, O.B.E., M.A.

Honorary Treasurer.

W. MCCLELLAND, C.B., O.B.E.

Ordinary Members of Council.

T. E. ALLIBONE, D.Sc., Ph.D.
L. G. BRAZIER, Ph.D., B.Sc.
E. S. BYNG.
H. J. CASH.
P. DUNSHEATH, O.B.E., M.A., D.Sc.
D. Z. DE FERRANTI.
P. GOOD.
PROF. F. WILLIS JACKSON, D.Sc., D.Phil.
PROF. W. J. JOHN, B.Sc. (Eng.).
PROF. R. O. KAPP, B.Sc.
E. LEETE.
A. L. LUNN.

Ordinary Members of Council—(*Continued*).

P. L. RIVIÈRE.
C. RODGERS, O.B.E., B.Sc., B.Eng.
H. W. SWANN.
C. D. TAITE.
G. A. WHIPPLE, M.A.
A. P. YOUNG, O.B.E.

Chairmen and Past-Chairmen of Local Centres.

Argentine Centre:
W. E. TREMAIN.
*C. G. BARKER.

China Centre:
J. HAYNES WILSON, M.C.
*C. S. TAYLOR.

Irish Centre:
T. A. MCLAUGHLIN, Ph.D., B.E., M.Sc.
*J. W. O'NEILL.

Mersey and North Wales (Liverpool) Centre:
W. HOLTTUM, M.Eng.
*E. L. MORLAND.

North-Eastern Centre:
H. G. A. STEDMAN.
*F. A. ORCHARD.

North Midland Centre:
W. DUNDAS.
*J. W. ATKINSON, I.S.O.

North-Western Centre:
O. HOWARTH.
*W. FENNELL.

Scottish Centre:
PROF. S. PARKER SMITH, D.Sc.
*W. J. COOPER.

South Midland Centre:
H. JOSEPH.
*H. FAULKNER, B.Sc.

Western Centre:
T. E. ALGER.
*H. S. ELLIS.

* Past-Chairman.

Chairmen of Sections.

F. E. J. OCKENDEN (*Meter and Instrument*).
F. W. PURSE (*Transmission*).
E. B. MOULLIN, M.A. (*Wireless*).

Secretary.

W. K. BRASHER, B.A.

Assistant Secretaries.

F. W. HEWITT, M.Sc.; A. E. RAYNER.

LOCAL CENTRES AND SUB-CENTRES.

ARGENTINE CENTRE.

Chairman.—W. E. TREMAIN.
Hon. Secretary.—R. G. PARROTT, Tucuman 117, Buenos Aires.

CHINA CENTRE.

Chairman.—J. HAYNES WILSON, M.C.
Hon. Secretary.—J. A. MCKINNEY, c/o Shanghai Power Co., P.O. Box 404, Shanghai.

IRISH CENTRE.

Chairman.—T. A. MCLAUGHLIN, Ph.D., B.E., M.Sc.
Hon. Secretary.—R. N. EATON, 1, Foster Place, College Green, Dublin.

MERSEY AND NORTH WALES (LIVERPOOL) CENTRE.

Chairman.—W. HOLTTUM, M.Eng.
Hon. Secretary.—W. PARRY, M.Eng., "Scaur," Birkenhead Road, Gt. Meols, Hoylake, Wirral, Cheshire.

NORTH-EASTERN CENTRE.

Chairman.—H. G. A. STEDMAN.
Hon. Secretary.—L. MELLOR, "Burn Brae," Heworth, Gateshead, Co. Durham.

Tees-Side Sub-Centre.

Chairman.—M. CLINE.
Hon. Secretary.—H. SHAW, "Glenholme," Boosbeck, Saltburn, Yorks.

NORTH MIDLAND CENTRE.

Chairman.—W. DUNDAS.
Hon. Secretary.—K. C. COOP, M.Eng., 36, Park Place, Leeds, 1.

Sheffield Sub-Centre.

Chairman.—F. S. NAYLOR, B.Sc.
Hon. Secretary.—A. C. BOSTEL, 23, Stumperlowe Mansions, Fulwood, Sheffield, 10.

[*Continued on page (III) of Cover.*

THE ST. BARTHOLOMEW'S HOSPITAL X-RAY TUBE FOR ONE MILLION VOLTS

By T. E. ALLIBONE, D.Sc., Ph.D., Member,* F. E. BANCROFT,† and G. S. INNES, B.Sc., Associate Member.‡

(*Paper first received* 6*th January, and in revised form* 27*th February*, 1939; *read before* THE INSTITUTION 13*th April, before the* NORTH-EASTERN CENTRE 27*th March, and before the* NORTH-WESTERN CENTRE 18*th April*, 1939.)

SUMMARY

A description is given of the high-voltage X-ray tube and one-million-volt d.c. generator installed in the Mozelle Sassoon X-ray Therapy Department of St. Bartholomew's Hospital. The building contains a treatment room located between two generator rooms. The central portion of the X-ray tube, from which the X-ray beam emerges, traverses the treatment room and projects into each generator room. The generator rooms each house 500-kV d.c. generators. The X-ray tube and thermionic rectifiers used in the d.c. generators are evacuated continuously by oil diffusion pumps, and the whole apparatus is readily demountable. Removable filament assemblies are fitted to the rectifiers and facilitate rapid replacement of filaments; and a special cathode with 6 interchangeable filaments has been developed for the X-ray tube to avoid frequent admission of air into the tube during filament replacements. The tube is now used continuously at 1 000 kV and has been operated experimentally at 1 100 kV. Several structural changes have been made for reasons stated later, and the performance of the tube is fully described. Curves relating X-ray output with voltage and filtration by metallic filters are given, and a radiograph is included to illustrate the capabilities of the tube if applied to industrial radiography.

Comparisons are made between this tube and high-voltage tubes operating in other parts of the world.

CONTENTS

CONTENTS—*continued*

(1) INTRODUCTION

X-rays and the gamma-rays from radioactive substances have been used for many years for the treatment of cancer and other diseases, and considerable research has been done to improve the technique of treatment. On the electro-physical side, X-ray tubes suitable for operation at increasingly higher voltages have been developed and the present paper describes a high-voltage tube designed to operate at voltages between 300 and 1 000 kV, and now installed at the St. Bartholomew's Hospital, London.§

Before describing the equipment, the physical considerations which have warranted the development of higher-voltage X-ray tubes will be summarized. The action of X- and gamma-radiations on tissue is not fully understood, but it is suspected that the reactions consequent upon the absorption of the rays are caused by ionization and dissociation of the complex molecular structure of tissue. The efficacy of X-ray and gamma-ray therapy depends mainly on the relative lethal action of these rays on living pathological and normal tissue. Various types of cellular structures respond differently and all possible avenues of treatment have to be explored, such as the variation of response, if any, with the wavelength of the X-ray or gamma-ray beam. The basic reason for constructing a very high-voltage X-ray tube is to produce X-rays of as short a wavelength as possible so that the biological properties of these rays may be investigated.

Hitherto the differences in results of treatment by X-rays and gamma-rays cannot be ascribed solely to difference in wavelength of the rays, as another important factor inherent in the two sources of the rays complicates the issue. This factor is the great difference in intensity between the gamma-ray beam from even a large concentration of radium, and the X-ray beam from an ordinary tube. The gamma-ray intensity is so low by comparison that the use of gamma-rays is almost confined to treatments where the source of the rays can be either introduced into or placed in intimate contact with the tissue to be irradiated. The X-rays, on the other hand, on account of their great intensity, can be used for treatment well below the surface: the source of the rays can be located at a considerable distance from the surface so that the beam at the surface is only slightly divergent, and the intensity of rays at a depth below the surface is

* High-Voltage Research Laboratory, Metropolitan-Vickers Electrical Co., Ltd.
† Physics Research Laboratory, Metropolitan-Vickers Electrical Co., Ltd.
‡ St. Bartholomew's Hospital, London; formerly High-Voltage Laboratory, Metropolitan-Vickers Electrical Co., Ltd.

§ The equipment is installed in the Mozelle Sassoon Department, and was the gift of Mrs. Meyer Sassoon.

of the same order of magnitude as at the surface (say 40 %). By giving treatments in a number of different directions in turn, the dose at a depth can be brought up to the required value. Any increase in voltage applied to an X-ray tube decreases the average wavelength of the beam, and increases the penetrating power and therefore the depth dose compared with the surface dose. It also increases the absolute intensity of the beam so that, in turn, the distance between the tube and the patient may be increased, and in consequence the percentage depth dose is further increased. As the intensity of the beam decreases with the square of the distance, the fullest advantage of these factors can only be taken if the available energy is high, far higher than from concentrations of as much as 5 grammes of radium, so one is forced to turn to the extra-high-voltage X-ray tube for the necessary energy at short wavelengths.

It is interesting to note how the gamma-rays compare in wavelength with X-rays from the usual 200-kV tube,

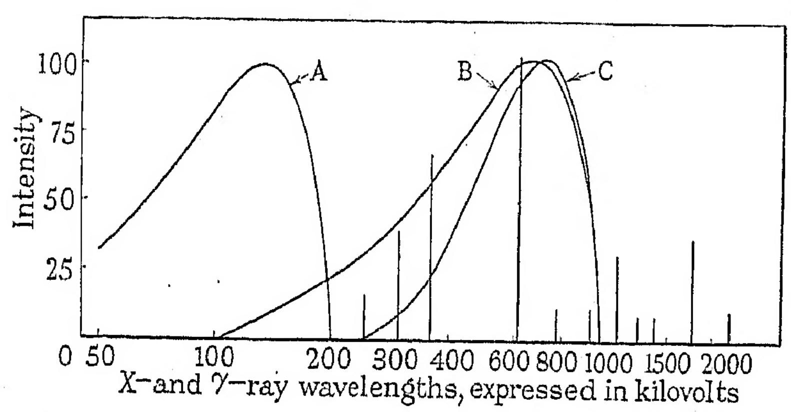


Fig. 1.—Comparison of X-ray and gamma-ray spectra.

A. Spectrum of X-rays from tube operating at 200 kV.
B. Spectrum of X-rays from tube operating at 1 000 kV.
C. As B, filtered by 5 mm. lead.

The vertical lines represent the gamma-ray spectrum of Ra-B and Ra-C, and the length of the lines is proportional to the intensity. All curves are given to a maximum ordinate of 100.

and from a tube operating at 1 000 kV. The gamma-rays usually employed in gamma-ray therapy are those from radium B and C, and they consist of a heterogeneous group of radiations of wavelengths varying from 5×10^{-9} to 5×10^{-8} cm., corresponding to voltages of 2 000 to 200 kV. The relative intensities of these gamma-rays is given in Fig. 1 to an arbitrary scale, plotted against wavelength expressed in kilovolts, the most intense gamma-ray (620 kV) being given an ordinate of 100. In the same figure are plotted intensity distribution curves A and B corresponding to the X-ray outputs of tubes operating at 200 and 1 000 kV respectively; these are also plotted to a maximum ordinate of 100. Whereas the energy of the gamma-rays is concentrated into a few wavelengths, that from an X-ray tube is spread over the whole spectrum of wavelengths with a lower limit set by the voltage applied to the tube, and it will be seen that for a tube operating at 1 million volts the crest of the intensity/wavelength curve corresponds roughly to the wavelength of the most intense gamma-ray. The curve can be modified by absorption of the beam in metallic filters, and curve C corresponds to curve B after the rays have been filtered by 5 mm. of lead (the maximum intensity of curve C is maintained arbitrarily at the same value, 100). It will be noticed that now the energy of the resultant beam is more concentrated in the shorter wavelengths. With this amount of filtration the intensity of the emergent beam is reduced to a fraction of its original value, and therefore it is desirable to have as high an X-ray output as possible in order to keep the time of treatment reasonably short. The tube and generators described in this paper have been designed to give a satisfactory output at all voltages between 300 and 1 000 kV, so that if any optimum voltage for treatments were found between these values, the tube could be used efficiently at that voltage. In addition, as one of the objects of the tube was to produce the shortest wavelengths possible for a given voltage, it was decided to energize the tube from a source of constant potential rather than from alternating or pulsating potentials. It should be stated, however, that recently tubes have been specially designed for operation on pulsating potential, and, by restricting the flow of current except during a fraction of the voltage cycle at its crest, such tubes give radiation of nearly the same effective wavelength as tubes operating at the same constant potential.

(2) PRINCIPLES UNDERLYING THE DESIGN OF THE X-RAY TUBE

The first attempt to increase the operating voltage of vacuum tubes above the 200-kV level was made in 1925 by Dr. Coolidge,* of the General Electric Co., Schenectady, who constructed a type of Lenard tube which operated at 300 kV. This tube was sealed off from the pump and was used in conjunction with an induction coil. One of the authors (T. E. A.) constructed a similar electron tube which operated at 400 kV in conjunction with a Tesla transformer, but this tube was evacuated continuously, first by mercury pumps (1927) and then in 1928 by oil diffusion pumps using the new Apiezon oil discovered by Burch.† The principle of continuous evacuation offers great advantages for high-voltage tubes as it allows of great flexibility of design and reduces maintenance costs; its earlier application was only withheld on account of the expense of liquid air as a refrigerant for the mercury vapour, and with the advent of Apiezon oil this objection was removed.

In the United States several high-voltage tubes have been constructed and used partly for physical research and partly for medical and biological research. Dr. Coolidge‡ introduced the cascade principle in 1928 by mounting three 300-kV tubes in series, each separately energized by induction coils: the electrons therein travelled some 8–10 ft. before striking the target at the end of the third tube. A similar tube was eventually installed in the New York Memorial Hospital,§ but this tube was evacuated by mercury pumps. Later models were installed at the Mercy Hospital, Chicago, and at the Swedish Hospital, Seattle. These were evacuated by Apiezon oil pumps and all of them were operated at 600–800 kV from pulsating potential generators. Lately the Seattle tube has been modified by Rose and Loughbridge‖ (1936) by the addition of a grid control on the filament assembly so that electron acceleration only occurs at the crest of the voltage wave. This considerably reduces the effective wavelength of the emergent X-ray beam.

* See References (1) and (2). † *Ibid.*, (3).
‡ *Ibid.*, (4). § *Ibid.*, (5). ‖ *Ibid.*, (6).

A tube of an entirely different type was constructed by Lauritsen and Bennett* (1928) at the Institute of Technology, California. The cathode of this tube was brought so close to the anode that at the operating potential (about 600 kV) auto-electronic emission occurred at the cathode. As the tube was operated from a high-voltage transformer, bursts of current occurred at each negative crest of the voltage wave. The output was, however, erratic as it depended on the speed with which the discharge developed. Lauritsen later constructed a double-ended vertical tube energized to 1 000 kV by two transformers. The principle of the short electron path was retained, but instead of relying upon auto-electronic emission a hot filament was used in the cathode. The insulators between the central earthed section and the cathode and anode were of glass, and intermediate electrodes, which floated at intermediate potentials, shielded the glass from electronic bombardment. The central earthed section comprised a steel cylinder which was located in a corridor, and four horizontal X-ray beams were available for simultaneous treatment.

A single-ended tube operating at 500 kV (d.c.) was installed by the Kelley Koett Co. at the General Cancer Clinic, Lincoln, Nebraska. The tube was vertical with one porcelain insulator envelope, the acceleration being done in one stage across a short electron path. The target was earthed, and four horizontal X-ray beams were available for simultaneous treatment. The constant potential was produced by 7 cascaded rectifier units. Initially the tube was evacuated by mercury pumps, but it has since been modified considerably: it now has a mid-potential electrode and operates on Apiezon oil† (1936): the operating voltage is 700 kV (d.c.). Similar tubes were installed at the Harper Hospital, Detroit, and at the Soiland Clinic, Los Angeles.

At the University of California Medical School at San Francisco, Sloan and others‡ (1935) built a tube operating on a radically new principle. The generator consisted of a tuned transformer operating at 6 Mc./sec., the transformer being built into a large evacuated steel tank. A filament shielded by a biased grid was located in the wall of the tank and a target was mounted at the high-voltage terminal of the secondary winding directly opposite the filament. This tube operated up to voltages estimated from absorption curves to be 800 kV, though higher values have been more recently claimed§ (1937). Four horizontal ports and one vertical port were provided. There are a few other tubes now operating at high voltages, but the examples cited cover the established principles of construction and operation.

For atomic disintegration, Cockcroft and Walton‖ (1932) had constructed a tube and generator for 600 kV (d.c.), the tube having two stages of acceleration and the generator being very similar to the generators described later in this paper. The ionic path was long; only positive ions were accelerated, and the tube was not used to generate X-rays. In Washington, Tuve, Hafstad, and Dahl¶ (1935) constructed a 12-stage positive-ion tube operated with a 1 200-kV electrostatic generator of the type described by Dr. van de Graaff. This design has recently been followed at the Huntingdon Memorial Hospital, Boston,* where an X-ray tube is installed which operates up to 1 200 kV. The tube employs 20 stages of acceleration, and the electrons travel over a path 15 ft. in length. In Berlin, Brasch and Lange† built a multi-acceleration tube which operated from an impulse voltage generator, but as a gas discharge developed with each application of voltage the average wavelength of the emitted X-rays is likely to have varied greatly. Recently Bowers and van der Tuuk‡ have described a sealed-off tube for 600 kV, similar to the early double-stage Coolidge tube.

The tube described in this paper was designed in 1934–35, at which time none of the above-mentioned tubes was operating at 1 million volts and it was not easy to assess the relative merits of the few tubes then in operation. It was considered desirable that the source of X-rays should be available at as short a distance as possible, and that the tube should be shockproof and rayproof. Continuous evacuation by oil diffusion pumps was a foregone conclusion to reduce maintenance costs and allow of great flexibility of design.

In order to locate the source of the X-rays as definitely as possible on one small area of the target or anode of the tube, the authors were in favour of bringing the filament as near to the target as possible, rather than of adopting the alternative design in which the electrons are accelerated by successive stages through a total distance of the order of 10 ft. Their experience with commercial continuously evacuated X-ray tubes for 250 kV,§ and experimental tubes operating at higher voltages, indicated that voltages of at least 300 kV, and probably 500 kV, could be maintained between concentric cylindrical electrodes *in vacuo* without excessive degassing of parts. It appeared, therefore, that 1 million volts could probably be applied to a tube consisting of three or four concentric cylindrical electrodes, the outer cylinder being earthed, the inner cylinder being at 1 000 kV, and the intermediate electrode or electrodes being at the appropriate intermediate potentials. Alternatively the tube could consist of an outer earthed vacuum cylinder with the cathode and target projecting into it from opposite ends, each being supported by insulators capable of withstanding 500 kV. With the single-ended tube the diameter of the necessary vacuum cylinder would be approximately twice that of the double-ended tube. With regard to the generators, the single-ended tube would require a generator for 1 million volts to earth, while the double-ended tube would require two 500-kV generators of opposite polarity. The major proportion of the space required for a high-voltage constant-potential generator, where air insulation is employed between the various components, is dictated by the necessary clearances to the surrounding walls. With the type of rectifier/generator developed by the authors, the volume of the generator room for a 1-million-volt generator would be $2 \cdot 5$ times that required for the two 500-kV generators together. The relative volumes of the space required for the ends of the two types of tubes would be approximately the same.

Taking the above factors into account, it was decided to build a double-ended tube, with an earthed central

* See Reference (7). † *Ibid.*, (8). ‡ *Ibid.*, (9). § *Ibid.*, (10). ‖ *Ibid.*, (11). ¶ *Ibid.*, (12).

* See Reference (13). † *Ibid.*, (14). ‡ *Ibid.*, (15). § *Ibid.*, (16).

section, close to which the treatments would take place. The anode and cathode were both to be insulated for 500 kV to earth, and to extend into the central section to within a few inches of one another. If further division of potential were found to be necessary, means for making this division were visualized. The diameters of the cathode, anode, and central section, were fixed from consideration of the electrical gradients at their surfaces, as will be explained later.

A method of changing filaments without breaking the vacuum in the tube had already been developed by one of the authors (F. E. B., 1937), and since the evacuation of such a large tube from atmospheric pressure would take about 2 hours the filament-changing device was incorporated for the first time in this tube.

Several methods of cooling the target in the anode, which would be at 500 kV to earth, were considered. The most simple would have been to circulate oil through an insulating pipe from the ground to the target and to cool the oil by a water-cooled heat exchanger at earth potential. It was felt, however, that carbonization of the oil might occur immediately behind the target, owing to the great concentration of energy there, and, furthermore, in the event of the target being punctured the tube might have been so contaminated with oil that the cleansing of the tube would have been exceedingly laborious. It was therefore decided to install a closed water-cooling system operating at target potential, comprising a radiator and fan capable of dissipating 10 kW. The decision has been justified by subsequent events: a target punctured and, before the target could be removed, a gallon of water had entered the tube. Within 5 hours of re-evacuation the tube was operating again at 700 kV.

The authors' experience with continuously evacuated X-ray tubes indicated that a pumping speed of 20 litres per sec. was sufficient for a tube of 100 litres volume and 20 sq. ft. surface area. As the present tube has a volume of 8 000 litres and a surface area of 120 sq. ft. (ultimately 180 sq. ft.) it was decided to employ two oil-diffusion pumps, each of 180 litres per sec. pumping speed, to cope effectively with the gases released from the surfaces of the tube under electrical bombardment. In addition, for experimental purposes it was decided to fit two vapour condensation traps (liquid air or solid CO_2) between the pumps and the tube. These high-speed pumps were each backed by a high-backing-pressure oil-diffusion pump and a rotary pump. A large single-stage rotary pump connected directly to the tube was also provided to exhaust the tube from atmospheric pressure.

With regard to protection against very short-wave-length X-rays very little information was available, so the authors made use of the findings of the League of Nations Health Organization (Publication No. C.H. 1054). For a voltage of 1 000 kV and current of 1 mA, absorption by 17 cm. lead is stated to be necessary to reduce the radiation to the safe figure of 10^{-5} r/sec.* at a distance of 50 cm. from the target. As the medical authorities were anxious that the minimum distance between target and patient should be as small as possible, a lead thickness of 12 cm. was decided upon, and a rotary type of X-ray shutter was designed in preference to one sliding to-and-fro which would have added more than 15 cm. to the minimum "focal-skin" distance. The lead shielding was to be in the form of a cylinder surrounding the central earthed section of the X-ray tube and capable of being rotated about the axis of the tube. It was decided by the medical authorities that only one port should be incorporated in this cylinder from which the X-ray beam could emerge, rather than the several ports employed in some of the tubes in the United States. By rotation of this cylinder the port could be brought to the required direction for treatment, or could be further rotated to such a position that the emergent beam would be absorbed by a block of lead when not required. This system obviated the necessity for removing the voltage from the tube between treatments.

* A definition of the r unit is given in the footnote on page 667.

(3) DESCRIPTION OF EQUIPMENT

(a) Layout of Plant

The layout of the X-ray tube and d.c. generators is shown in Fig. 2. The earthed central section of the X-ray tube horizontally spans the treatment room, which is 11 ft. wide. The anode projects into this section of the tube from the positive generator room on the left, and the focal spot on the target is located at the mid-point of the central section. From the focal spot X-rays radiate in all directions. The port in the rotatable lead cylinder surrounding this section is located in the same vertical plane as the focal spot perpendicular to the longitudinal axis of the tube, so that by rotation of the cylinder an X-ray beam can be obtained emerging in various directions in this plane. In addition, a part of the treatment room floor comprising a platform 10 ft. by 12 ft. under the tube can be traversed vertically from a height of 4 ft. above floor-level to 3 ft. below. With these various adjustments it is possible to treat any part of a recumbent patient with a beam directed at any angle.

The ends of the X-ray tube project into the positive generator room on the left and the negative generator room on the right. Here the central metallic section of the tube ends, and porcelain insulating sleeves clamped on each end of the central section insulate the cathode and anode for 500 kV. To avoid excessive mechanical strain on these sleeves, the anode and cathode are supported from the ground by insulators.

The d.c. generators each consist of four 250-kV thermionic valves, three 250-kV and one 125-kV condensers, one 125-kV (peak) transformer, and the necessary filament-supply generators. The condensers, valves, and filament current generators, are all mounted in vertical columns. Each 500-kV generator is connected to the X-ray tube through a high resistance to limit short-circuit currents.

The apparatus rooms and treatment room are enclosed in walls of barium sulphate concrete to absorb the X-rays emerging from the tube. The control room is placed in line with the treatment room, the intervening wall being of barium-sulphate concrete 18 in. thick. Patients may be seen from the control desk by means of a periscopic system of mirrors,* and a two-way microphone system operates between control room and treatment room.

* Designed by Mr. T. Smith, F.R.S., of the National Physical Laboratory. Aluminized by the Metropolitan-Vickers Electrical Co., Ltd.

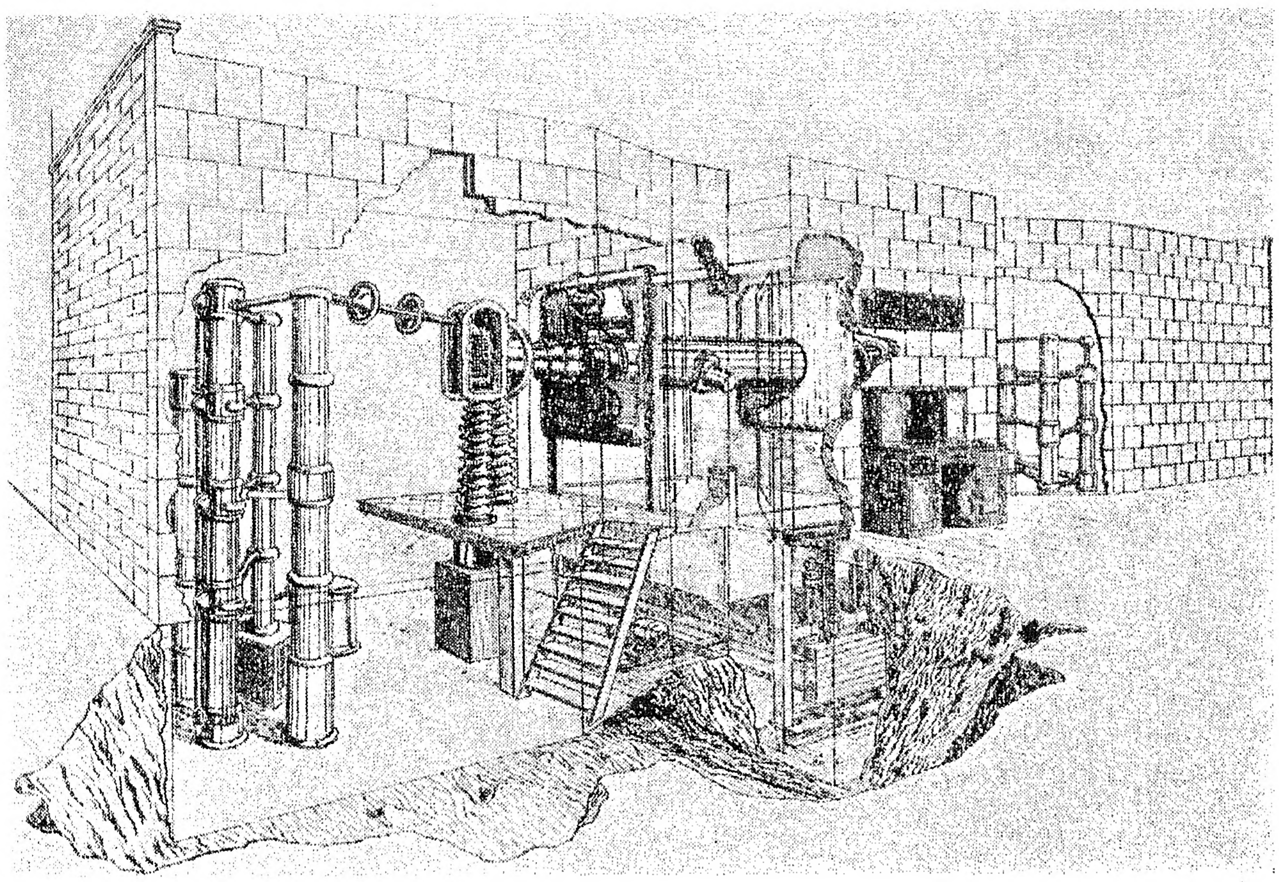


Fig. 2.—Perspective view of X-ray tube, generators, and control room.

(b) The X-Ray Tube

(i) General Arrangement.

The general arrangement of the tube is shown in Fig. 3. The tube spans the treatment room T at a height of 6 ft. above floor-level and extends through the walls to the apparatus rooms A1 and A2. The openings in the walls are provided with steel frames on which is supported the central earthed section (1) of the X-ray tube, which consists of a 14-in. diameter steel tube 17 ft. in length. On these frames is also supported a double-walled steel cylinder (2), the space between the walls of which is filled with lead to absorb unwanted X-rays; and surrounding this is a light steel cylinder (3) on which are carried an ionization chamber to record the intensity of the X-ray output of the tube, filters, and beam-limiting diaphragms.

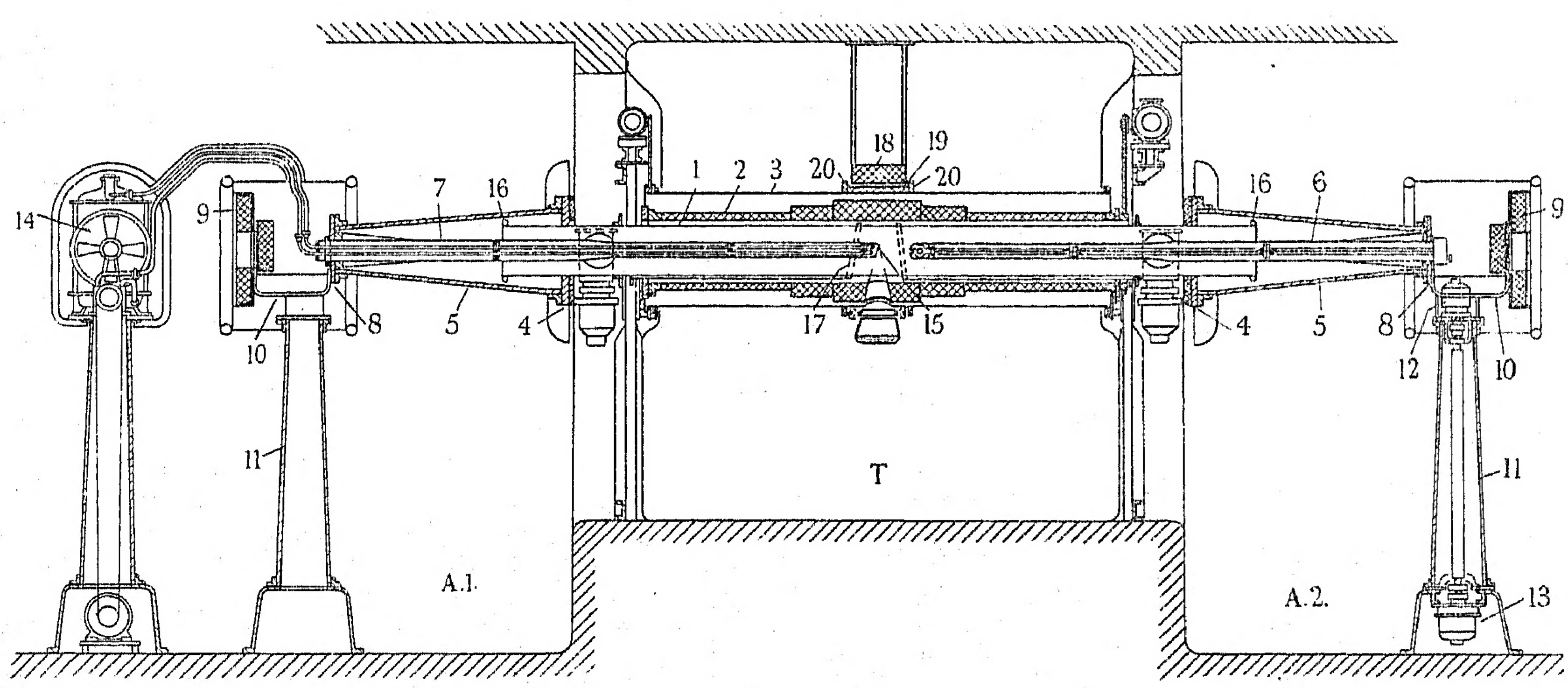


Fig. 3.—Section of tube.

Each end of the central earthed section of the tube—referred to as the body cylinder—has a flange (4) to which a conical porcelain insulator (5) is jointed by a special vacuum joint, and the cathode (6) and anode (7) are secured to the end plates (8) at the remote ends of these insulators. These electrodes are concentric with

the body cylinder; the anode terminates at a point such that the focal spot on the target is midway between the walls of the treatment room, and the cathode terminates at a point 7 in. away from the extreme end of the target. The overhanging weight of each electrode is balanced by a lead disc (9) attached to a cradle (10) secured to the end plate of the insulator, and the whole weight of the electrode assembly is carried by the porcelain insulating column (11).

A filament-current generator (12) is mounted at the top of the insulating column at the cathode end of the tube, and is driven through an insulating shaft by a motor (13) at the base. At the anode end of the tube a radiator (14), fan, and pump for circulating the cooling water for the target, are mounted together on a porcelain insulating column to prevent vibration from being transmitted to the tube. The fan and pump are driven by an insulating belt from a motor at the base of this column. The water is forced through copper pipes to cool the target (15) at the end of the anode. A detailed description of the component parts is given below.

(ii) The Body Cylinder.

The central earthed section of the X-ray tube was built up from three equal cylinders (rolled from automobile-body finish sheet steel $\frac{1}{8}$ in. thickness) welded together. Each section was completed separately, the end sections having their flanges and pumping branches welded on, and each was ground smooth and polished internally. The smooth polished surface on the inside of the tube is important for two reasons: first, it avoids the possibility of sharp points which may increase the local potential gradient and so increase the auto-electronic emission, especially at the positive end of the tube where the body cylinder is at a negative potential with respect to the anode; and secondly, it enables the surface to be readily cleaned. The cylinder extends beyond the end flanges, and each end is fitted with a stress distributor (16) fabricated from 2 in. diameter steel tubing and highly polished.

The part of the cylinder extending for about 6 in. on each side of the radial centre-line is water-cooled by means of a copper tube (17) soldered on to the body cylinder, and this serves to dissipate heat generated by secondary electronic bombardment (if any). The body cylinder is fixed to one of the supports only, the other end being free to slide on its support to allow for differential expansion

(iii) The Protective Lead Cylinder.

Several methods were considered for the construction of the protective lead cylinder. The attachment of sheet lead or suitably interlocked cast lead blocks to a steel cylinder did not appear to be satisfactory, so it was designed as a double-walled cylinder and the space between filled with lead shot. It was constructed in two half-sections with a longitudinal joint, flanged and bolted together (see Fig. 4 in Plate 1, facing page 664) in a temporary mounting. The inner diameter is uniform, and the outer diameter varies in three steps giving radial depths of 2 in., 3·5 in., and 6 in., so that all direct rays pass through at least 6 in. of the annular space within the cylinder. Experiments indicated that the best packing coefficient could be obtained with lead shot of two sizes, $\frac{3}{8}$ in. and $\frac{1}{32}$ in. diameter, and a figure of 80 % was obtained. Thus all direct rays pass through at least 12 cm. of lead. When the cylinder was completely filled the noise of the moving shot during rotation was negligible. The port at the centre of the cylinder was formed by welding in the frustum of a steel cone of apex angle 30°.

The cylinder is mounted on ball-bearing flanged wheels and is rotated by means of a chain drive, motor, and gear box, one revolution occupying $\frac{1}{4}$ minute. The motor is fitted with an electromagnetic brake, and although the cylinder weighs 8 tons it can be stopped within $\frac{1}{8}$ inch in the circumference at the outer extremity of the port. The cylinder rotates only in one direction, so that in giving short exposures of X-rays it is analogous to the focal-plane camera shutter and gives equal dosage over the whole irradiated field.

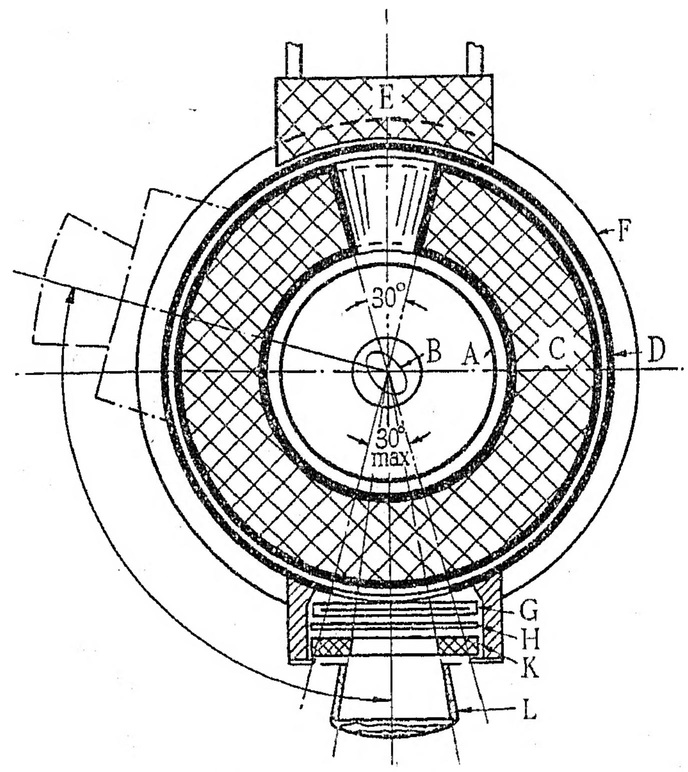


Fig. 5.—Diagrammatic cross-section through centre of X-ray tube.

A. Central section of evacuated envelope.
B. Target.
C. Protective lead cylinder.
D. Applicator cylinder.
E. Lead block.
F. Lead rim.
G. Ionization chamber.
H. Filter.
K. Lead diaphragm.
L. Applicator.

(iv) The Applicator Cylinder.

Surrounding the protective lead cylinder is the light steel cylinder on which applicators or beam-limiting devices are carried. This cylinder is also mounted on ball-bearing flanged wheels and is likewise driven by a chain and motor gearbox unit. As the target of the X-ray tube does not rotate, X-rays of uniform intensity are only available over about 100° of arc, so this cylinder is made to rotate through 110° as shown in Fig. 5. It is controlled from the treatment room and is rotated only when the port of the protective lead cylinder is directed upwards (the " rest " position), in which position the emergent X-ray beam is absorbed by the lead block (18 in Fig. 3) suspended from the ceiling. The applicator turn-table is mounted at the centre of the cylinder and at this point a further lead shield (19) consisting of a band of lead 1 in. thick and 20 in. wide is fitted round the

applicator cylinder to reduce the intensity of the main beam of X-rays as the lead cylinder rotates before and after each treatment.

The protective lead cylinder, which is controlled by push-buttons on the control desk, is electrically linked to the applicator by cam-operated switches; it cannot be operated from the treatment room or when the treatment room doors are open. When the applicator cylinder has been set at the required angle for treatment and the treatment room doors have been closed, the protective lead cylinder may be rotated from its rest position by pushing a button on the control desk, and the cam switches ensure that it is stopped with its port in true alignment with the applicator port. At the termination of treatment the cylinder is further rotated in the same direction back to its rest position.

The lead block suspended above the tube is thick enough to absorb the beam passing through the lead on the applicator cylinder, and is wide enough to absorb the ensuing sideways scattered rays. Parallel to the axis of the tube the scattered rays are absorbed by two rings of lead (20), of 1 in. × 2 in. section, fixed to the applicator cylinder.

An ionization chamber (G in Fig. 5) is mounted permanently on the applicator cylinder and covers the entire port, so that all the emergent X-ray beam traverses the chamber. Metallic filters (H) and lead diaphragms (K) are also mounted over the port on this cylinder. Applicators or compressors (L) are mounted on a turntable fixed to the applicator cylinder, so that they may be rotated about the axis of the emergent beam. A general view of the treatment room is given in Fig. 6 (Plate 2).

(v) The Cathode.

The cathode and anode are each insulated from the body cylinder by a porcelain sleeve 60 inches in length. The jointing of these called for some experimental work. For small joints lapped surfaces sealed with low-vapour-pressure grease or bitumen may be used, but for joints in excess of 8 in. diameter this technique was not considered to be practicable. Experiments with portland-cemented steel/porcelain joints vacuum-sealed with bitumen on the outside showed that very lengthy evacuation would be necessary to remove air and water from the cement. Successful joints were made by caulking rings of lead into the annular gap previously filled with cement, and sealing with bitumen. Another method more recently developed consists of shrinking suitably-shaped steel flanges on to the porcelain to give the necessary mechanical support, and of bolting these flanges to the body cylinder or the end plates to which the cathode or anode are secured. The shrunk-on joints are sealed with bitumen and the demountable joints are oil-sealed. This method is illustrated in Fig. 7. The porcelain cylinder (A) is first ground externally for a few inches axially at each end as accurately as possible. No attempt is made to grind the porcelain to a specified diameter to close limits, but when it has been ground its average diameter is computed from a number of measurements and the steel flange (B) is machined to suit with an interference tolerance of 0·0007 in. per inch diameter. The porcelain is heated to 60° C. and the steel flange to 150° C., at which temperature it is easily placed over the porcelain. The parts are allowed to cool slowly and the sealing channel (D) is then filled with special bitumen. The steel flange having been attached to the porcelain cylinder this flange is jointed to the flange (C) by means of a lead gasket (E), which is sealed with oil (G) retained by a cork gasket (F). The elasticity of the cork ensures that the full pressure holding the joints together is applied to the lead gasket.

The cathode consists of a steel support tube 4 in. diameter and 12 ft. in length fastened to the end plate which is bolted to the steel ring on the porcelain insulator. The end near the target is fitted with a hemispherical nose which has in it a centre hole ½ in. diameter to focus the electron beam on to the target. The other end fastened to the end plate is stiffened by four steel webs

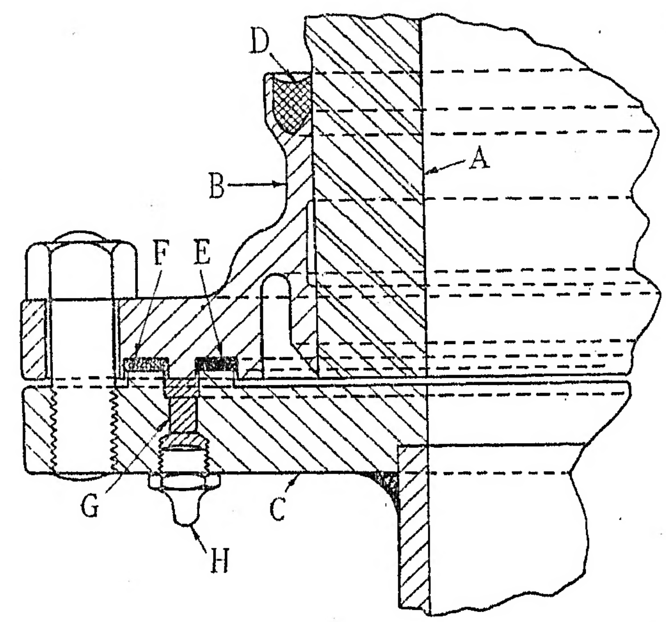


Fig. 7.—Part cross-section showing flanged joint between porcelain and steel cylinders.

A. Porcelain cylinder
B. Steel flange (shrunk on).
C. Flange on steel cylinder.
D. Bitumen seal (Apiezon W).
E. Lead gasket.
F. Cork gasket.
G. Sealing oil (Apiezon J).
H. Oil-gun nipple.

over which fits a thin sheet-steel conical stress distributor. The cathode and its end plate are bolted to a steel cradle (10 in Fig. 3). The moment of the cathode about the point of support of the cradle is balanced by the moment of the lead weight (9) also attached to the steel cradle which is supported on the porcelain insulating column (11). The cradle is made to slide parallel to the tube axis to facilitate erection and to allow for longitudinal expansion. The lead weight is in the form of a number of discs 30 inches in diameter fixed into a sheet steel case mounted perpendicularly to the axis of the tube. It serves the additional purpose of absorbing those primary X-rays almost parallel to the tube axis which are not intercepted by the lead protective cylinder. In the centre of the discs a hole is provided through which the filament-holding device is inserted into the cathode steel support tube. This hole is covered by a hinged lead block.

The filament-holding device is located in position by the contact of its optically flat end-flange with a corresponding flat on the cathode end-flange, and the joint is made vacuum-tight with an Apiezon sealing compound.

The filament-changer is made in three sections to facilitate its removal from the tube when filaments have to be replaced. The filaments are held as shown in Fig. 8 (see Plate 3) in a hexagonal head which is mounted on a spindle on which it may be rotated by means of bevel gears and a shaft running the full length of the filament-changing unit. A rotatable oil-sealed cone is used to transmit the rotary motion through the end cover, so that by turning a knob on the end cover the filament head is rotated and a pointer indicates the number of the filament in use. One leg of each filament is fixed in the steel body of the filament head, which is electrically connected to the cathode-supporting tube. The other leg of each filament is fixed in a small steel block insulated from the head, and a contact brush connects the block of the filament in use to an insulated conductor rod. When any one filament is in use the remaining five are disconnected. A small tray catches broken pieces of tungsten to prevent them from interfering with the rotation of the head. Little difficulty has been experienced in the operation of this device. The filament current supplied by the generator mounted on the support insulator is controlled by a rheostat mounted close to the generator (12 in Fig. 3), which in turn is adjusted by an insulated shaft operated by a motor at the base of the support insulator.

(vi) The Anode.

The anode consists of a steel tube 5 in. diameter and 13 ft. long bolted to an end plate, cradle, and lead balance-weight, in a manner similar to that described for the cathode. The tube carries the target unit, which consists of the target head and water-circulating pipes with supporting discs and an end plate which is lapped flat to make a vacuum-tight demountable joint. Thus the target may be removed like the filament head, by breaking a joint of small diameter without disturbing the general assembly of the tube.

The target is a bimetal disc of 0·020 in. thickness of gold and 0·060 in. of copper. Similar discs have been found to be satisfactory for lower-voltage X-ray tubes. The disc is hard-soldered to a copper cup the end of which is formed at 30° to the normal. The cup is soft-soldered to a copper block into which the water-circulating pipes are hard-soldered, so that the cup can be easily removed for target replacement. Turbulence of water flow is ensured behind the target by greatly reducing the cross-section of the water passage at this point.

It has been found that a flow of 10 gallons per minute, producing a pressure-drop of 10 lb. per sq. in., provides adequate cooling of the target; a temperature-rise of 15 deg. C. occurs with a dissipation of 4 kW at the target. A water-flow relay is connected in the water circuit.

(vii) The Pumping Plant.

The high vacuum is maintained by continuous evacuation with Apiezon oil-diffusion pumps backed by mechanical pumps. Details of these have been given in a recent paper,* but a new extra-high-speed diffusion pump (Type 04B) was employed for the first time on this tube. A diagrammatic cross-section of this is given in Fig. 9. Its pumping speed is 180 litres per sec. measured in a wide pipe just above the cowl. This high-speed pump is backed by a high-backing-pressure diffusion pump (Type 02) backed in turn by a two-stage rotary pump. There are two complete pumping plants, one at each end of the body cylinder, and they are joined to the tube through 8 in. diameter pipes and cylindrical condensation traps. These traps could be filled with a refrigerant for check experiments, but as they offered no serious impedance to gas flow they were left permanently in position when not in use. Near the junction of the side pipe to the tube a metallic gauze was fitted into the pipe to act as an electrode in the event of a gas discharge, which otherwise might terminate on an oily surface inside the pump and cause cracking of oil.

Between the 02 diffusion pump and the two-stage rotary pump is fitted a flat vacuum tap operated by a hydraulic-ram mechanism, the water valve of which is controlled by means of an electromagnet. A drum switch is fitted to the spindle of the tap-operating mechanism in order to change over certain electrical connections associated with the protective gear under the different conditions, (*a*) when the tap is closed and (*b*) when the tap is open.

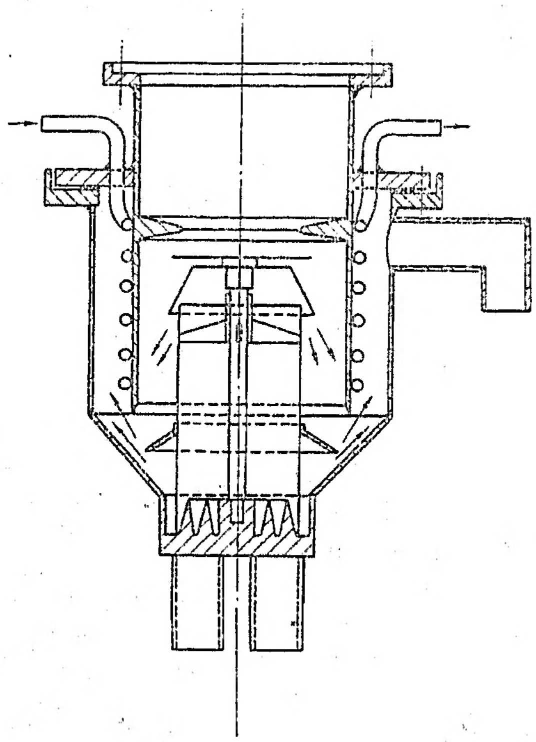


Fig. 9.—High-speed oil diffusion pump, Type 04B.

Preliminary evacuation from atmosphere is effected by a 40 cu. ft./min. single-stage rotary pump. The pressure falls to 0·1 mm. in 30 min., and to 0·04 mm. in another 30 min.; at this pressure the diffusion pumps are automatically switched on, and are operating in 20 min.; the tube can be energized in another 20 min. Normally, if the tube has not been at atmospheric pressure the tube may be energized within 40 min. from the moment the pumps are switched on. It has been found convenient and satisfactory to leave the pumps switched on all night so that there is no delay each morning.

(viii) Protective Relays.

A number of relays are incorporated in the equipment directly associated with the X-ray tube to prevent

* See Reference (18).

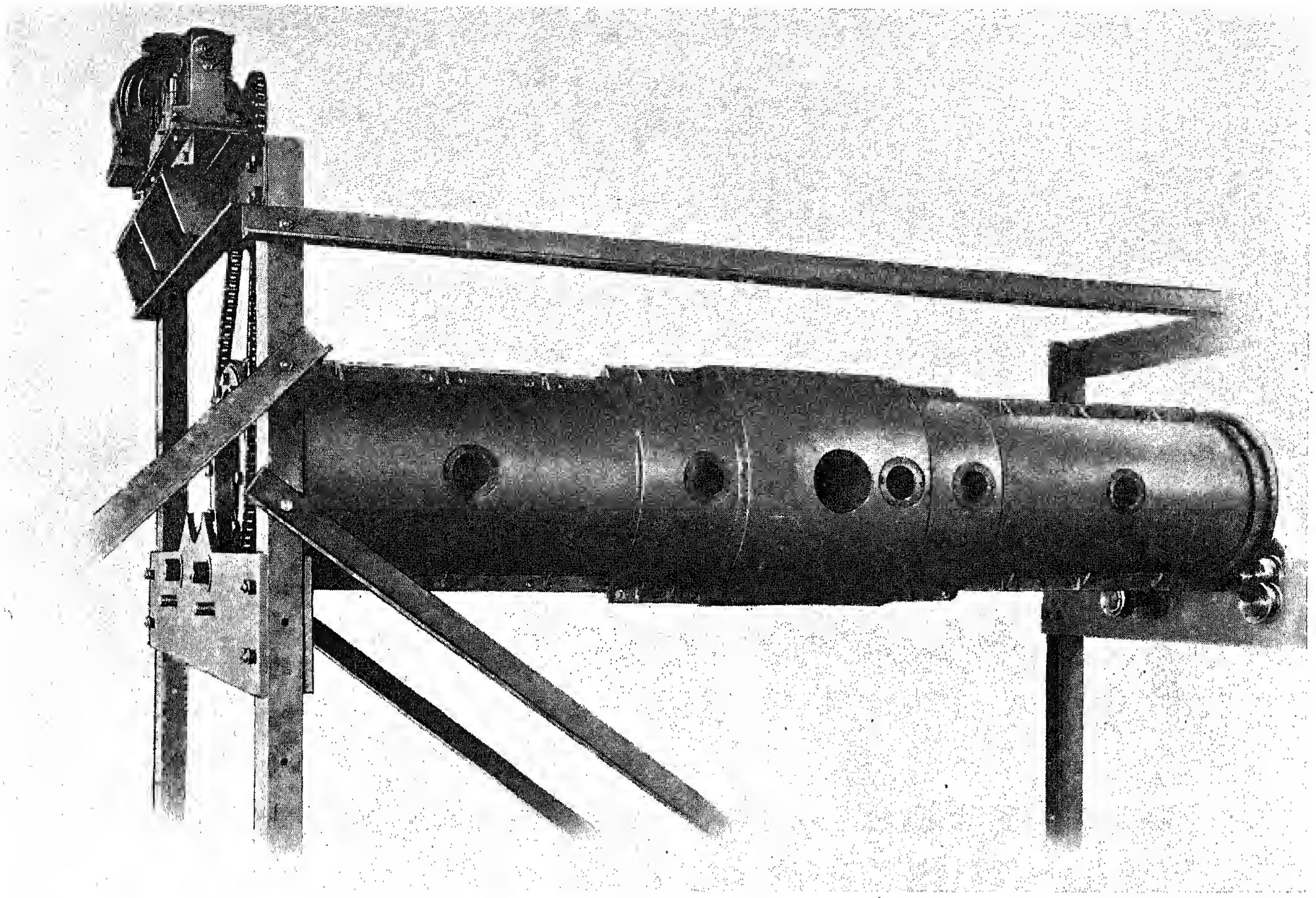


Fig. 4.—Protective lead cylinder mounted in a temporary stand. (Note the central aperture and ports for filling the cylinder with lead shot.)

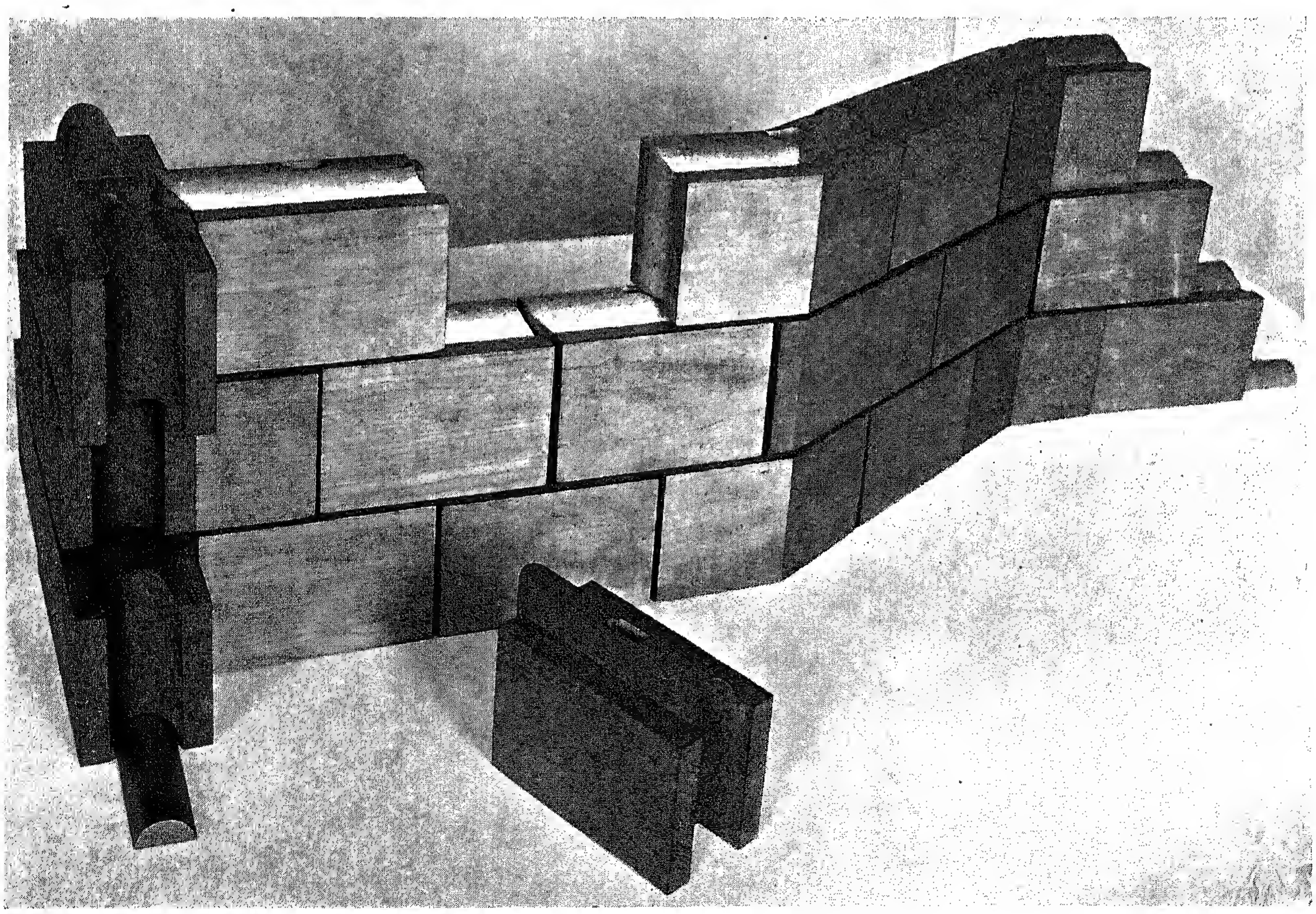


Fig. 13.—Model assembly of interlocked barytes concrete blocks.

Plate 2

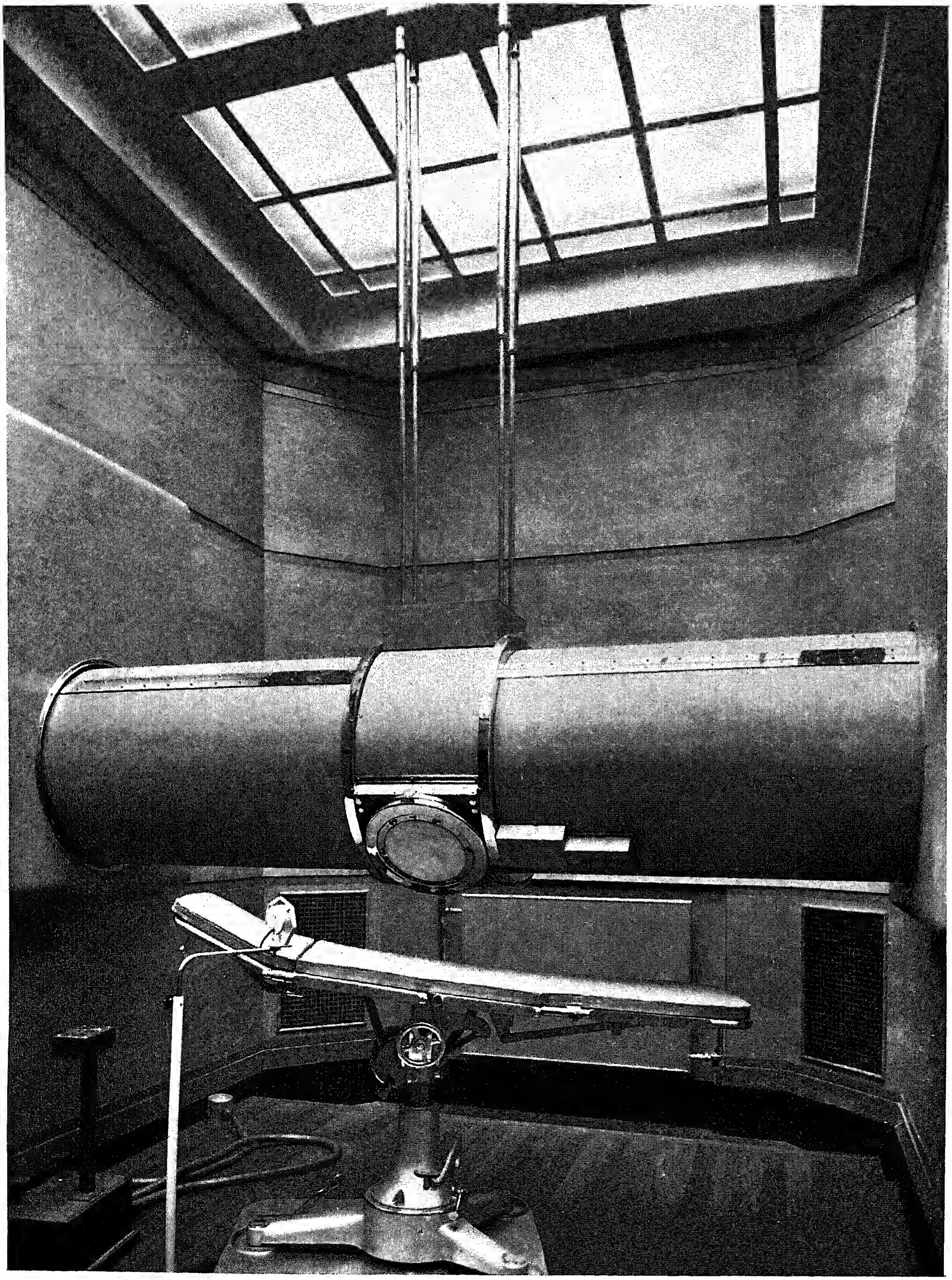


Fig. 6.—X-ray tube in treatment room.

Plate 3

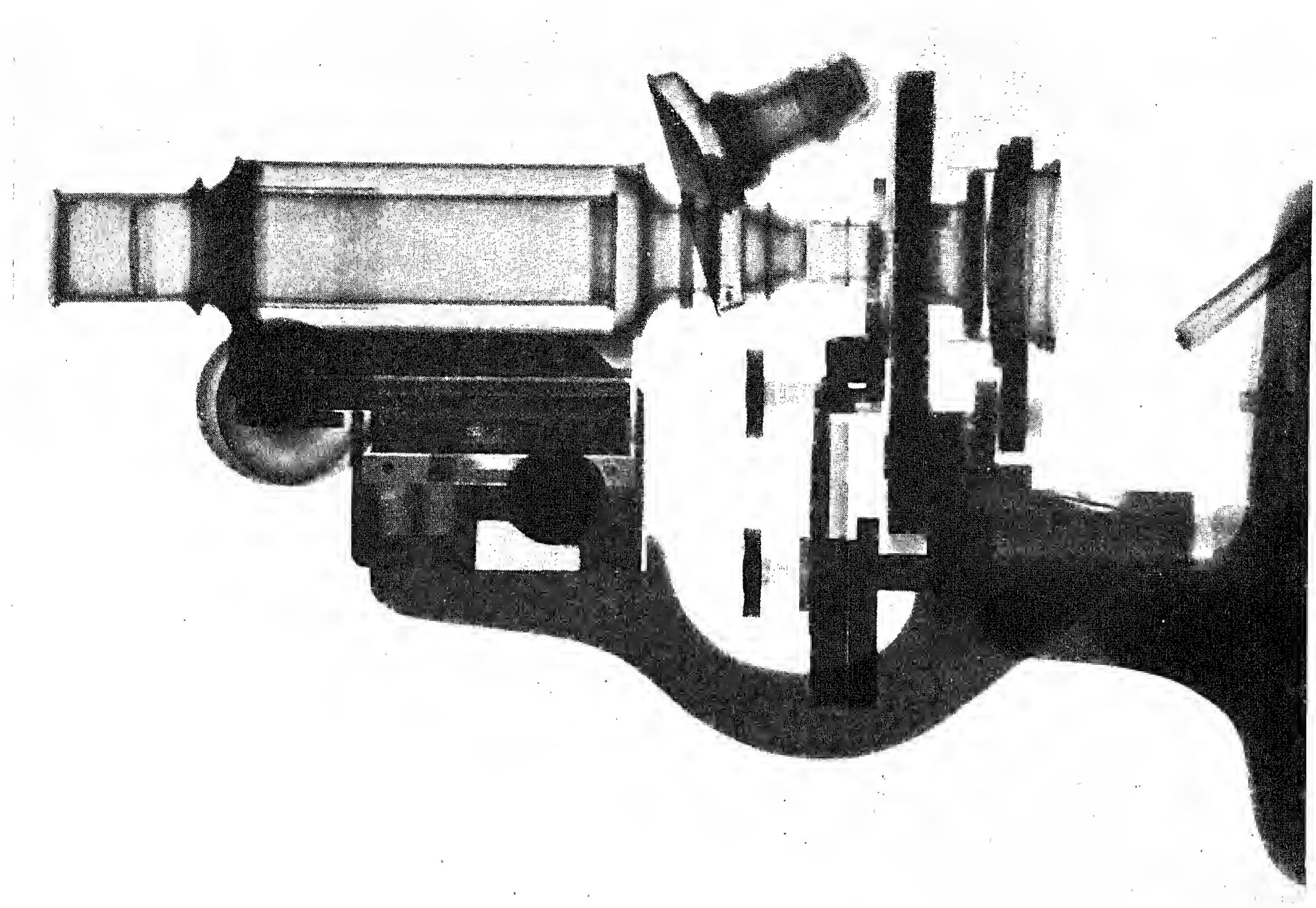


Fig. 25.—X-radiograph, exposure 2 minutes at 3 metres from tube, 700 kV, 3 mA.

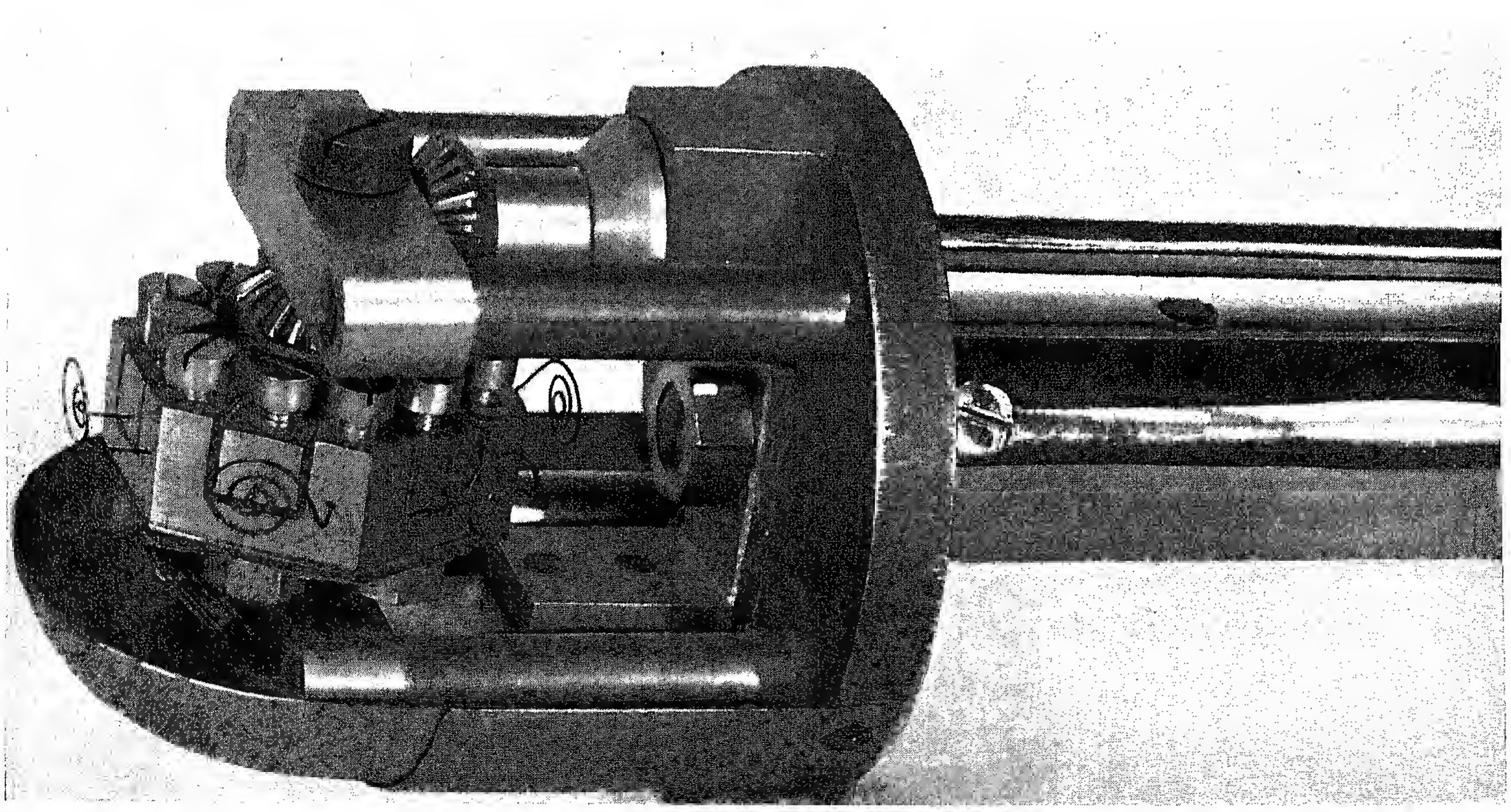


Fig. 8.—Filament-holder carrying 6 interchangeable filaments.

Plate 4

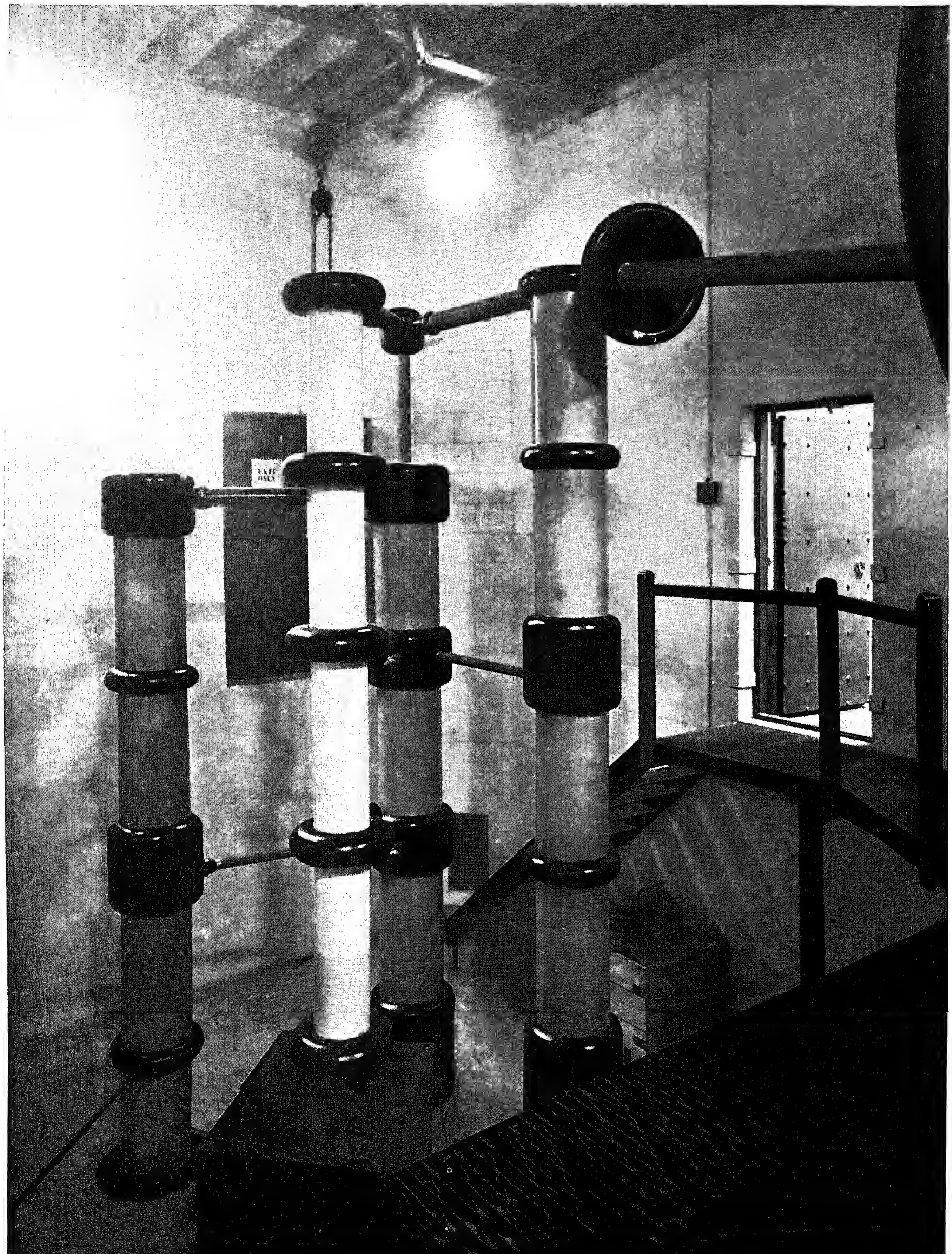


Fig. 11.—The 500-kV d.c. generator on site.

damage in the event of faults occurring in this apparatus. A centrifugal switch prevents operation of the tube when the radiator cooling fan is running below an optimum speed, and a vane-type water-flow relay operates if the supply of cooling water to the target should fail for any reason. The operation of these and the H.T. overload relays is transmitted to L.T. contacts at ground level via insulated rods.

Pirani-gauge vacuum relay elements connected in bridge circuits are fitted in each vacuum system, and changes in gas pressure operate sensitive d.c. relays; by varying the voltage across the bridge the relay may be set to operate at any desired gas pressure within a limited range. The vacuum relays are arranged to open each vacuum tap after the rotary pump has produced a low enough pressure in the vacuum system up to the closed vacuum tap. When the tap has opened and the gas pressure in the whole tube is at a sufficiently low value a second vacuum relay causes the diffusion-pump heaters to be switched on, provided there is a sufficient water flow through the pump jackets. A bimetallic-strip thermal relay is fitted to the base of each diffusion pump, and the contacts are set to close when the pump base is at the correct temperature for ebullition. Since it is fairly safe to assume that if the pump base is at the correct temperature and if the vacuum pressure behind the 02 pump is low enough to operate the Pirani gauge relay the pressure in the tube will be less than 10^{-4} mm., then the high-potential generators may be switched on, provided the target cooling-water system is in operation. The cooling water for the diffusion pumps is checked for flow by passing the outlet through a bucket-type water relay.

The diffusion pump system is made fully automatic so that three switches on the control desk start respectively the three sequences of operations for the tube and the two generators.

(c) The High-Voltage Generators

Both generators are designed for 500 kV with respect to earth and are similar in all essential details except in their polarity. The circuit used (Fig. 10) is that due to Cockcroft and Walton (1932), but has been modified slightly by the addition of series resistances in the condenser circuits. It consists of a transformer for peak voltage V; four valves each capable of withstanding a reverse peak voltage of $2V$; and four condensers, three of which are designed for $2V$ (d.c.) and one for V (d.c.). The generator delivers a constant voltage of $4V$ (d.c.). The circuit is particularly suitable for continuously evacuated thermionic rectifiers, as all four rectifiers may be mounted on top of each other on the pumping plant. The generators for supplying the valve-filament currents and the condensers may be treated in a like manner. Fig. 11 (Plate 4) shows the complete assembly of the negative 500-kV generator.

The envelopes of the rectifying valves are porcelain cylinders 25 in. long, the end faces of which have been ground flat. Steel junction boxes with similar flat faces are located between adjacent envelopes and support the anode of one valve and the cathode of its neighbour, as shown in Fig. 12. The hollow anodes are of steel tube with flared end stress distributors, spaced 1·5 in. from similar stress distributors on the cathode assemblies. To avoid dismantling the rectifiers in order to replace the filament in any valve, a removable filament assembly, shown in Fig. 12, has been developed. The filament is mounted on a small assembly which screws into a steel head attached to a coiled spring. On the other end of this spring is fitted an end plate through which the filament supply is taken. The filament head is inserted into the side opening in the junction box and, propelled by the spring, slides easily up the bent steel cathode tube. A conical shoulder at the head of the cathode ensures that the filament is brought into the correct position opposite the anode, and a slight pressure is exerted by the spring to keep the assembly in position. The faces of the end plate and the side entry on the junction box are ground to optical flatness, and a good vacuum joint is made with an Apiezon bitumen.

The valves are evacuated by a pumping plant similar

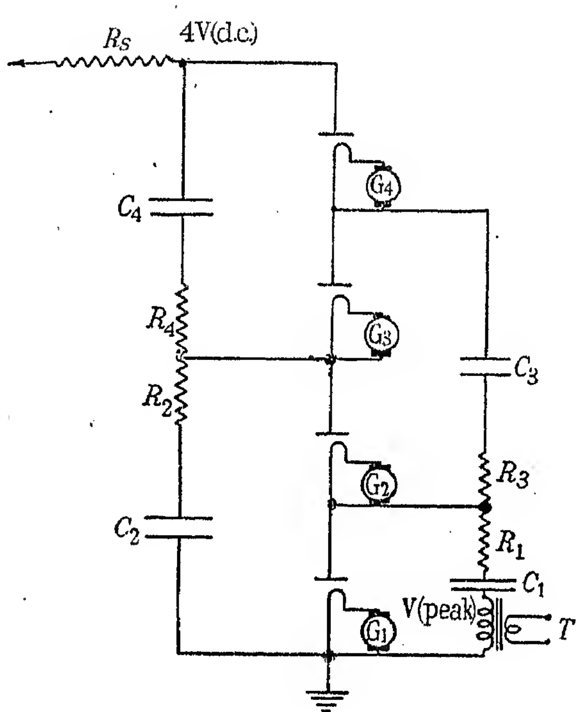


Fig. 10.—Circuit diagram of negative d.c. generator.

$C_1 = 0·047\ \mu$F. $C_2, C_3, C_4 = 0·023\ \mu$F.
$R_1 = 50\,000$ ohms. $R_2, R_3, R_4 = 50\,000$ ohms.
$R_s = 3·2$ megohms.

in essentials to that on the X-ray tube—a 180 litres/sec. Apiezon oil-diffusion pump backed by the appropriate pumps—and the pumping sequence is fully automatic. The filament-current generators are 150-watt d.c. machines mounted one above the other in stress distributors separated by bakelite cylinders capable of withstanding 250 kV each. The generators are driven by Tex-rope belts from a motor at ground-level. These belts are stressed at an average gradient of 100 kV per foot and have given no trouble in the 2 years during which they have been in operation.

It has been found essential to stabilize the circuit with resistances, and 50 000-ohm oil-immersed units are placed between each condenser, so that all circuits contain at least this value of resistance. In addition, a resistance of 3·2 megohms connects each generator to the X-ray tube. The values have been determined empirically and are sufficient to prevent damage to rectifiers or tube during short-circuits. It will be appreciated that an upper limit to the value of these stabilizing resistances is set by the

maximum permissible voltage-drop across them during the fraction of the cycle when current is passing through the valve. The maximum value would be 25 kV for a rectifier saturation current of 500 mA, but it is unlikely that the effective voltage-drop would be as high as this since the load current is only 5 mA: indeed, it is known that, even including the voltage-drop across the valves, the overall voltage efficiency is 86 %, expressed as 100 (output voltage) /4(peak input voltage) with a load of 5 mA at 500 kV output.

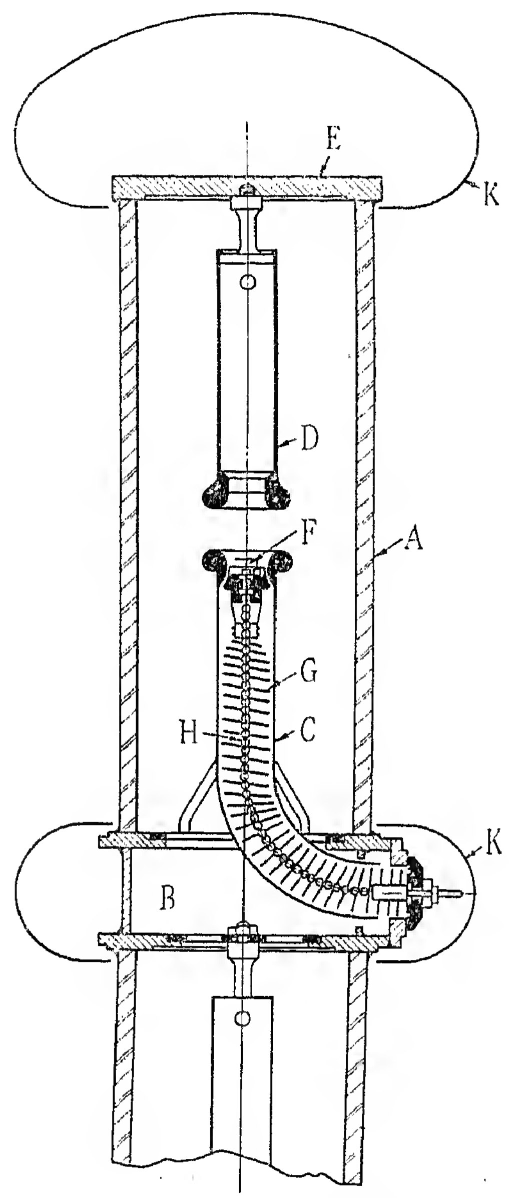


Fig. 12.—Cross-section of one element of rectifier stack.

A. Porcelain cylinder.
B. Junction box.
C. Cathode.
D. Anode.
E. End cover.
F. Filament.
G. Spiral spring.
H. Insulated conductor.
K. Stress distributors.

Protection against sustained overloads is accomplished by an overload relay in the primary circuit of the main transformer. Short-circuits of rapid development in the rectifier circuit are catered for by a sensitive h.t. overload relay connected in the outgoing lead from the main transformer. This relay operates contacts at ground-level via an insulated rod. Overloads taken by the X-ray tube operate another overload relay in the lead from the generator to the X-ray tube. In this way the equipment is protected against all types of overload and can be conditioned and operated by lay personnel.

The generators were tested to + 600 kV and − 700 kV respectively before erection on site, the voltage being measured by 50-cm. spheres. A combined test at ± 600 kV was made, in which case the voltage was measured by 100-cm. spheres. On site, voltage measurement is effected by two pairs of 50-cm. spheres, but recently high-resistance wire-wound, and also composition type, resistances of 2 000 megohms have been used in conjunction with electrostatic instruments mounted on the control desk to give direct indication of the voltage on each end of the tube, and also the summated voltage.

Although the rectifiers have been in use for over 2 years it has only been found necessary to clean them internally once. There is a certain amount of tungsten and carbon deposited on the inner walls of the insulator, and when this accumulates the rectifier becomes unstable and flashes-over repeatedly. So far, no porcelain insulator has failed. The presence of the resistances in each condenser circuit is no doubt responsible for the absence of appreciable metallic sputtering in the rectifiers. Filaments are normally replaced every 3 months, in which time they have operated some 500 hours. Their life is longer, but, since their cost is negligible, this regular replacement gives an added assurance of uninterrupted treatments.

The control of the generators is located in the control room (see Fig. 2), but the relays governing the automatic pumping sequences are in kiosks one in each apparatus room. Pre-reading voltmeters in the primary circuit of each transformer were relied upon to indicate the h.t. voltage until the resistance voltmeters were installed. The voltage on either generator may be raised (automatically) separately, or the two may be locked together. An illuminated diagrammatic indicator, shown in Fig. 2, serves to record the pumping sequences of generators and tube. In addition, gas pressure in the tube may be continuously measured by ionization gauge, and the X-ray intensity is indicated at the control desk.

(d) X-Ray Protective Measures

The degree of X-ray protection on the tube has already been specified. To absorb the main beam and scattered radiation during treatments, the treatment room was built with a barium-sulphate concrete cast into the form of interleaving blocks erected as shown in Fig. 13 (see Plate 1). The main beam intensity at the wall of the treatment room was anticipated to amount to 10*r* per minute, so that absorption by a factor of at least 10^4, and preferably 10^5, was desired. This is obtainable with 5 in. of lead, or 15 in. of barium concrete, and therefore the double wall of 9-in. thick blocks erected in the line of the main beam should be adequate. Elsewhere there was a single wall of 9-in. thick blocks all round the treatment room and on two sides of each apparatus room.

(4) OPERATION OF THE EQUIPMENT

(a) General

It was found that voltages up to 750 kV could be applied to the X-ray tube without any difficulty, and at this voltage currents of 7 mA could be passed from cathode to target without damage to the gold disc in the target. This voltage could be applied within 20 minutes from the completion of the pump-operating sequence, and

was often maintained without interruption for a complete day's operation. (Interruptions caused by momentary overloads are unimportant as the voltage may always be reapplied at once at the same value.) The X-ray output for constant tube current did not vary by more than 1 %.

Higher voltages could be applied to the positive end of the tube than to the negative end, because field currents are more easily produced at the negative electrode. These limited the voltage on the cathode to 330 kV and on the anode to 430 kV, but there was no evidence of field currents passing directly between cathode and target spaced 7 in. apart. With this separation a very uniform focal spot of 4·6 cm. diameter was obtained on the target. This did not change its position with time.

To reduce the field currents at higher voltages, modifications were made to the tube with a view to reducing the potential gradient at the surfaces of the concentric electrodes. These modifications consisted of introducing cylindrical electrodes X and Y between the body cylinder and the two high-voltage electrodes as shown by the full lines of Fig. 14. These were connected to the mid-points

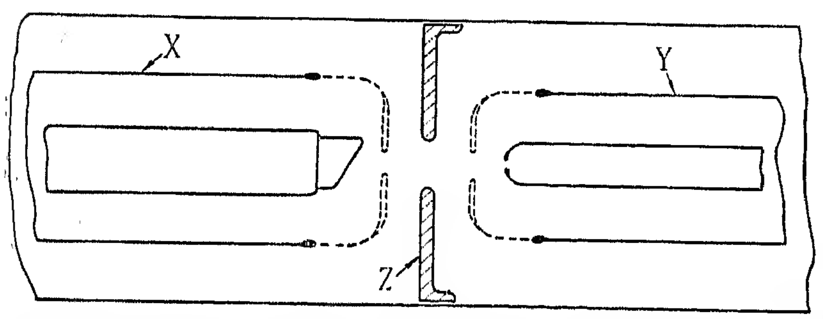


Fig. 14.—Diagrammatic representation of central section of tube, showing the supplementary electrodes X, Y, and Z, inserted to reduce field currents.

of the high-voltage generators through series resistances. As a result the limiting voltages were increased at least up to 450 kV at the cathode and 520 kV at the anode, but at a combined figure of 850 kV instability occurred for the first time between the cathode and anode. This instability has been removed by adding hemispherical ends (shown as dotted lines in Fig. 14) to the mid-potential electrodes, which, together with an earthed shield Z in the centre of the tube, effectively shield the cathode from the target. With this arrangement steady voltages of 1 100 kV have been applied without difficulties being experienced due to field currents: in fact, the upper limit of operation is not yet known. Details of operation of special interest are noted in the following sections.

(b) Measurement of the X-Ray Beam

Since it was not certain that the X-ray output for a given operating current and voltage would remain constant over any period, it was decided to incorporate a meter continuously indicating the X-ray output from the tube. This instrument would be used only as a control and would be calibrated against a standard each day, the reading being taken as the control figure for that day. As mentioned in Section 3(*b*) (iv), the ionization chamber for this meter was built into the applicator cylinder across the beam portal.

At the present time, X-ray dosage is measured by the quantity of ionization produced by the beam in a known mass of air.* This measurement is a function of the energy absorbed in the air, and is not necessarily a measure of the actual X-ray beam traversing the chamber. The quantities of electricity to be measured are small; for example, an X-ray beam of rather low intensity, say 1 roentgen per minute, produces an ionization current of only $5{\cdot}5 \times 10^{-12}$ amp. per cm^3 of air. Therefore, if possible, it is desirable to make the air volume of the ionization chamber large, and to measure the current by some direct method.

The chamber consists of three circular aluminium plates 0·5 mm. thick spaced 2·75 mm. apart, the central plate being insulated from the outer plates with amberoid bushes. As the diameter of the chamber (23·7 cm.) is larger than that of the X-ray beam at the applicator cylinder, the chamber casts no shadows and obtains a measure of the emergent beam. The active volume is 182 cm^3 so that, in the absence of any "wall effect" of the ionization chamber, the current would be $1{\cdot}01 \times 10^{-9}$ amp. for a beam of 1r per minute. Most of this current is collected with only 70 volts across the plates of the

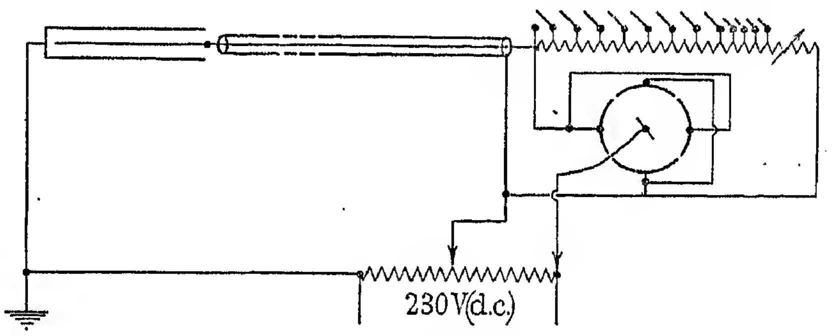


Fig. 15.—Circuit diagram of parallel-plate ionization chamber.

chamber, but to ensure the collection of all ions the plates are maintained at 170 volts. The ionization current is passed through a series resistance composed of a number of "grid-leaks" giving a variable resistance of 1 to 60 megohms, and a high-sensitivity precision electrostatic voltmeter (maximum sensitivity 2 volts full-scale deflection with vane bias of 200 volts) records the voltage across the series resistance. The resistance and instrument are connected to the chamber, as shown in Fig. 15, by 100 ft. of concentric cable provided with a buried sheath, so that the voltage appearing across the cable is only of the order of a few volts, thus simplifying leakage problems. The cable has a resistance to the sheath of 10^{14} ohms.

The ionization current as measured by an ionization chamber is generally greater than the current in an equal volume of air, due to the photo-electrons emitted by the walls of the chamber (the "wall effect"). This effect increases with the atomic number of the wall material and with increasing wavelength. At 700 kV the effect with the aluminium plate chamber is negligible, but at 200 kV it amounts to 2 % per 10 kV. The chamber was calibrated by comparison with a Siemens dosemeter, which was found to have no appreciable "wall effect" when checked against a chamber with air-equivalent boundaries.

* The unit quantity of X-rays, the "roentgen" or r unit, is that which, passing through a mass of 0·001293 gramme of air (1 cm^3 at N.T.P.), produces ions of each sign bearing 1 electrostatic unit of charge.

(c) Variation of X-ray Intensity with Voltage, Current, and Distance

Fig. 16 gives the variation of intensity of the X-ray beam with voltage. The beam is measured at 1 metre distance from the focal spot on the target and the measurement is taken "free" in air, with a field size of $16\cdot6 \times 16\cdot6$ cm. at the point of measurement. Curve A is for the minimum filtration provided by the body cylinder of the tube and the mid-potential shield: curve B is for an additional filtration of 2 mm. of lead supported on a thin steel sheet. The intensity for curve A varies approximately as the $2\frac{1}{4}$ power of the voltage for constant

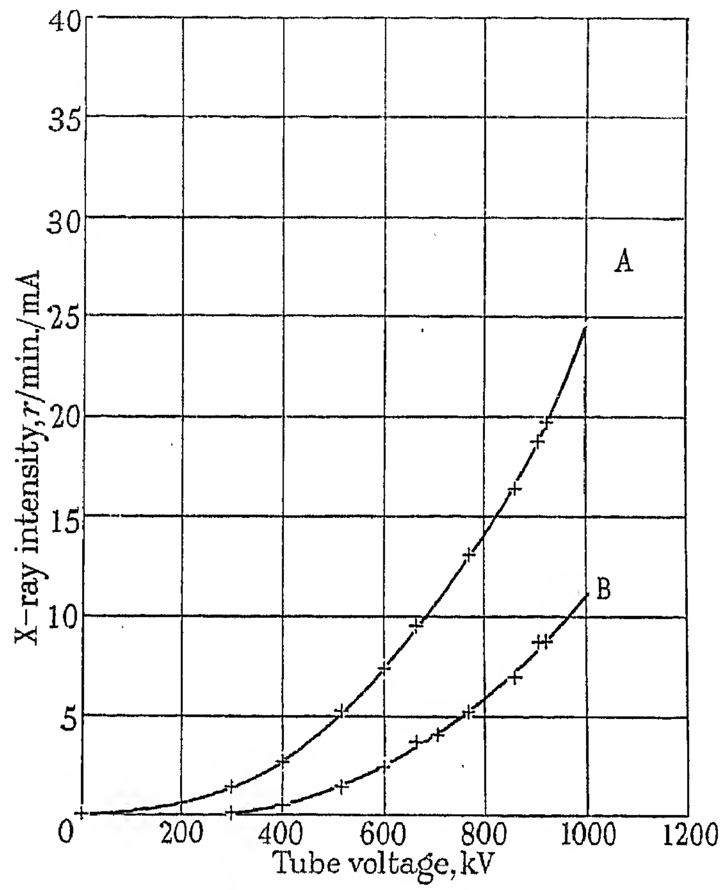


Fig. 16.—Variation of X-ray intensity with voltage.

A. Intensity after filtration by 4·1 mm. Fe and 1·5 mm. Al.
B. Intensity after additional filtration by 0·4 mm. Fe and 2·0 mm. Pb.
Beam measured "free" in air by a Siemens dosimeter at 100 cm. from target; field size 16·6 cm. × 16·6 cm.

current, so the efficiency of production of X-rays increases as $V^{1\cdot25}$. For curve B, $I \propto V^3$.

Measurement of the variation of intensity with voltage provided a useful method of observing the voltage at which field currents of appreciable magnitude flowed in the tube. Fig. 17, which relates to the first design of tube, shows the variation of intensity with cathode voltage, each curve relating to a fixed anode voltage. The current in the tube, measured by the milliammeter at the cathode, was kept constant at a low figure. In each curve, when the cathode voltage exceeds 300 kV the intensity departs from the original curve, and ultimately the intensity diminishes with increasing voltage. In this region of the curves the temperature of the filament has to be lowered with each increment of voltage; this indicates that, though the total cathode current was kept constant, the filament/target current diminished and the field current from the cathode to the body cylinder increased. This field current makes little or no contribution to the X-ray beam emerging from the port. All the curves show maximal intensities with cathode voltages of 310 to 330 kV. Further details of field currents are given in the next Section.

Up to the voltage at which field currents flow at the anode or cathode, the X-ray intensity per milliampere does not vary by more than 1 % with change of current from 0 to 6 mA. The current measured at the cathode is equal to that recorded at the anode, so no appreciable current (primary or secondary emission) flows to the central earthed section of the tube. (This experiment was done with the tube in its initial form and has not been repeated since the central diaphragm was put into the tube.)

It may be of interest to compare the output of the tube with that of the gamma-rays of radium. At 100 cm. from the target, the X-ray intensity "free" in air, after filtration by 4·5 mm. Fe—1·5 mm. Al—2 mm. Pb, is ·33r per minute with a $16\cdot6 \times 16\cdot6$ cm. field, with the

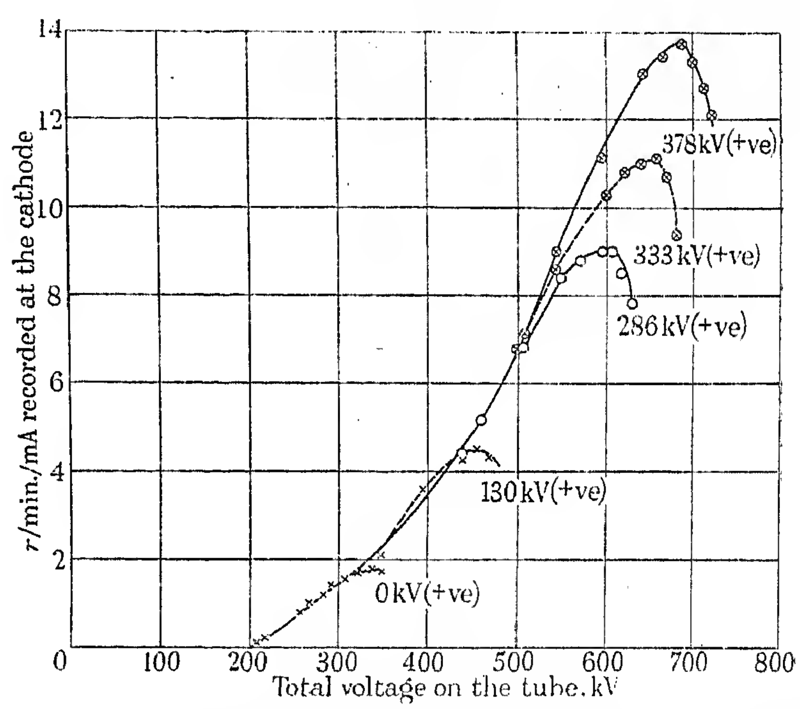


Fig. 17.—Variation of X-ray intensity with cathode voltage for different values of anode voltage (total current measured at the cathode kept constant).

tube operating at 900 kV, 4 mA. At the same distance the gamma-ray intensity after filtration by 0·5 mm. Pt is $1\cdot36 \times 10^{-2}r$ per minute per gramme of radium, so the X-ray beam is nearly equivalent in intensity to a beam from 2 500 grammes of radium, but of course the mean wavelength is longer.

The intensity in air varies inversely as the square of the distance from the target. The intensity I_d at a depth d below a given surface, where the intensity is I_0, is given by

$$\frac{I_d}{I_0} = \left(\frac{F}{F+d}\right)^2$$

where F is the distance of the target from the surface. This holds only in the absence of absorption and it follows that the ratio increases with increase of F. Owing to absorption, which is important foı all liquids and solids, the intensity at the surface is augmented by the radiation scattered backwards from below the surface,

and the intensity below the surface is diminished by absorption. With increasing voltage both these disturbing factors diminish, and therefore the ratio I_d/I_0 more nearly approaches the value obtained in air. This is shown in Fig. 18 for different values of F for 250-kV and 700-kV rays. The measured curve for gamma-rays is also given, but the actual intensities available preclude the use of radioactive sources at long focal skin distances. Fig. 18 indicates that with voltages above 700 kV appreciable increases in the depth dose at long focal skin distances should be obtained.

Shorter average wavelengths and an accompanying increase in depth dose can also be obtained by increasing the beam filtration, but a balance has to be struck between loss of the beam intensity and the relatively small increase in depth dose.* The optimum filter for an X-ray beam generated by 700 kV, 5 mA, after being filtered by the permanent tube filter of 3·2 mm. Fe—

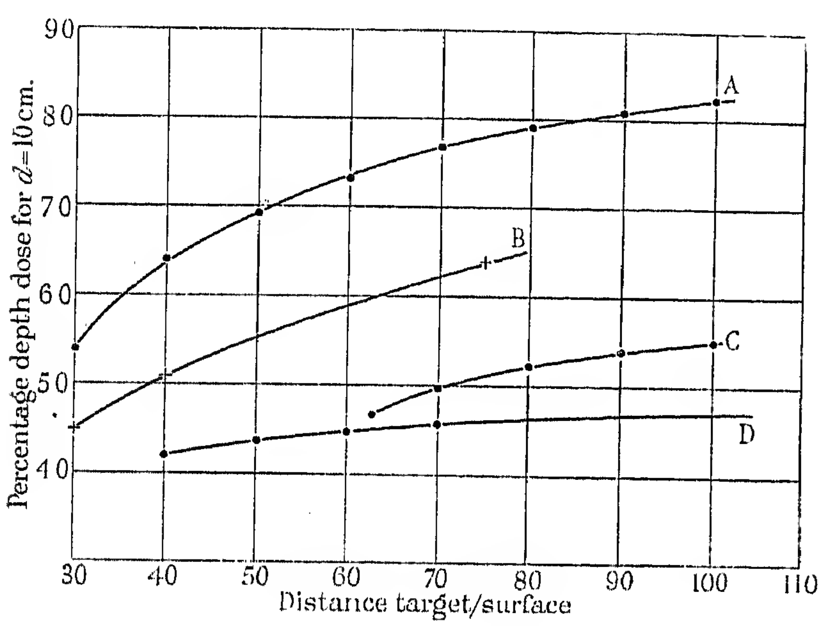


Fig. 18.—Variation of percentage depth dose with distance from focal spot.

A. Theoretical curve $I_{d=10}/I_{d=0}$, neglecting absorption.
B. Gamma rays (see Reference 20).
C. X-rays from present tube at 700 kV (Fig. 9 of Reference 21).
D. X-rays from tube at 250 kV (values extracted from Reference 22).
Curves C and D are taken for a field area of 300 cm^2

1·5 mm. Al, has been found to be 2 mm. Pb—2·4 mm. Sn—0·5 mm. Cu—1·0 mm. Al. This additional filtration altered the average wavelength of the beam from 0·051 Å.U. to 0·033 Å.U., with a reduction of the intensity from approximately 200r/min. to 50r/min. at 60 cm. from the target with a 10 × 10 cm. field (without back-scatter). With the addition of a further 3 mm. Pb in the above filter the average wavelength was altered to 0·027 Å.U., beyond which point there appeared to be little or no appreciable hardening of the beam with additional filtration. At 900 kV, after filtration by 4·5 mm. Fe—1·5 mm. Al—2 mm. Pb—2·4 mm. Sn—0·5 mm. Cu —1·0 mm. Al, the emergent beam has an average wavelength of approximately 0·0275 Å.U. These values of average wavelength have been estimated from the absorption coefficient of the beams in copper (see Mayneord and Roberts, 1935).†

* See Reference (21), Fig. 10.

† *Ibid.*, (23).

(d) Modifications Necessitated by Field Currents

The choice of diameters of the cathode, anode, and central section, was governed by several considerations. In the authors' design of 250-kV X-ray tubes in which the outer cylindrical electrode is 8 in. dia., an operating gradient of 80 kV/cm. at the surface of the inner concentric cathode had proved to be satisfactory. By doubling electrode diameters this gradient would be obtained with 500 kV between the cathode and the central section of the 1 000-kV tube. However, to provide the shortest possible focal skin distance the diameter of the central section was made only 14 in.

With regard to the diameter of the cathode, it is obvious from the formula for the gradient at the surfaces of concentric cylindrical electrodes that the gradient at the inner electrode is not very critically dependent on the diameter of the inner electrode, provided this is approximately $1/\epsilon$ of that of the outer electrode. The cathode was therefore made $4\frac{1}{4}$ in. O.D., tapering for mechanical reasons to $3\frac{1}{4}$ in. O.D. at the filament end. Calculating the gradient on the macroscopic dimensions and making no allowance for local departures from the cylindrical form of the electrodes, these dimensions result in gradients of 77 to 82 kV/cm. at the cathode, and 20 kV/cm. on the inside of the central earthed section.

With regard to the anode, if the cause of field currents is auto-electronic emission the important gradient will be that on the inside of the central section, which of course is negative with respect to the anode: there was no information regarding the maximum permissible gradients at anode surfaces, as tubes of similar construction had never been operated with the central electrode positive. The anode diameter was made somewhat larger ($5\frac{1}{4}$ in.) than the cathode merely because of its greater weight, but special consideration was given to the smoothness of the joint between the central section of the tube and the 8 in. dia. pipe leading from it to the 04 pump, where a high local gradient may be expected.

With regard to the distance between the end of the cathode and the target, some experiments made in the laboratory on the field current between concentric cylindrical electrodes showed that most of this current flows between the concentric cylindrical surfaces and not much from the tip of the inner electrode to the outer electrode, in spite of the high gradient at the tip. This is shown in Fig. 19 for $2\frac{1}{2}$ in. cathode and 8 in. anode for two different positions of the cathode within the anode. Check experiments showed that the current passed from the cathode to the surrounding cylinder, and not to the target, which is at the same potential as the outer cylinder. Thus the actual spacing between cathode and target in the 1 000-kV tube was not regarded as important: means for varying it were embodied, and at first it was made 7 in.

Experience showed that the field currents diminished with time, and a natural corollary is that the operating voltage may be increased with the passage of time. A typical set of readings of field current on different days is given in Fig. 20 for a $3\frac{1}{2}$ in. dia. cathode inside a 14 in. dia. anode. Each curve was taken at the end of a day's intensive bombardment of the electrodes; the condition of the tube improves fairly rapidly up to a certain

stage, beyond which further improvement is slow. In Fig. 21 field-current curves for the 1 000-kV tube prior to its modification are given for two dates separated by an interval of 7 months during which the tube was in

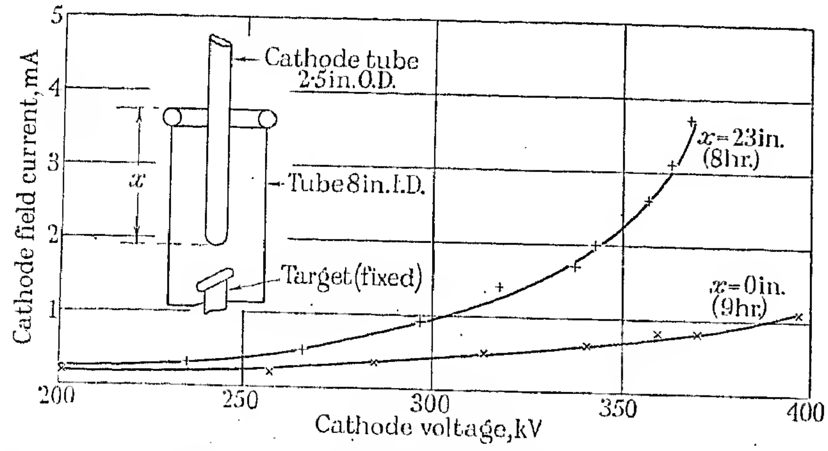


Fig. 19.—Variation of field currents with distance of penetration of cathode inside anode.

Time = hours of operation.
x = distance of projection of cathode into anode tube.

current. For example, in one instance the field current was doubled by merely rubbing the cathode surface once with No. 2 emery cloth, whereas the introduction of sharp points on the anode surface does not affect the current or the stability of operation. On another occasion, a small piece of copper wire lying inside the body cylinder of the 1 000-kV tube at the positive end gave rise to a field current of 10 mA at 40 kV. To improve the performance of the tube the additional electrodes already described were constructed. They were made from light-gauge sheet steel rolled to $8\frac{1}{2}$ in. dia., welded, and polished, and were held in steel sleeves. The original 500-kV porcelain insulators were each replaced by two 250-kV insulators, and the steel sleeves were bolted to the flanges at the junction of these insulators.

As a result of adding these insulators and the earthed shield between the cathode and anode, the voltage at either end of the tube may be raised above 500 kV: the actual upper limit is not yet known. The gradient at the cathode at − 500 kV is − 60 kV/cm., and at the outside of the mid-potential shield at the cathode end

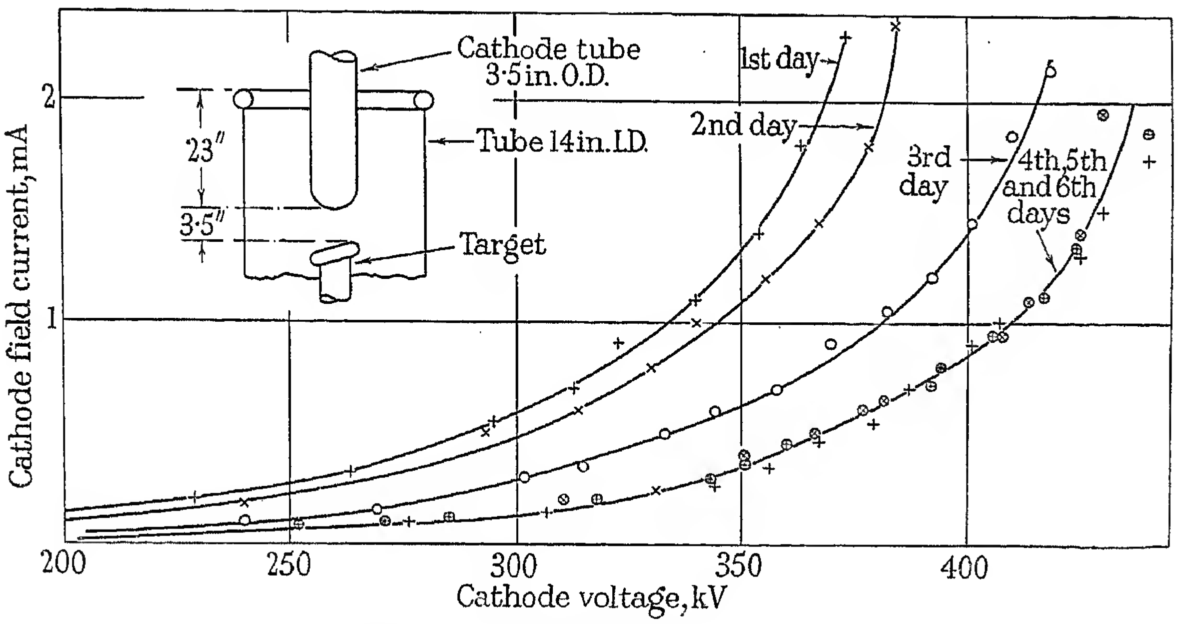


Fig. 20.—Variation of field currents with time.

repeated use. It will be seen that improvement took place at both ends of the tube, and it will also be observed that the currents start at a much higher voltage at the anode than at the cathode.

The upper limit of operation of the tube will be seen from Fig. 21 to be about − 350 kV and + 450 kV. This corresponds to a cathode gradient of − 57 kV/cm., an anode gradient of + 72 kV/cm., and a cathodic gradient on the inside of the central cylinder opposite the anode of − 22 kV/cm. These figures appear surprisingly low for the onset of auto-electronic emission,* but it must be remembered that the exposed areas are very large and have never been degassed at high temperatures. Thus the current of 0·3 mA at 350 kV at the cathode is equivalent to 4×10^{-8} amp./cm.^{2} if uniformly distributed over the cathode. The same current with the anode at 450 kV is equivalent to 10^{-8} amp./cm.^{2} from the surface of the body cylinder. A great deal of evidence points to the negative electrode as being the source of the field

* See Reference (24).

it is 50 kV/cm., both values being well below the operating cathode gradients for 250-kV X-ray tubes.

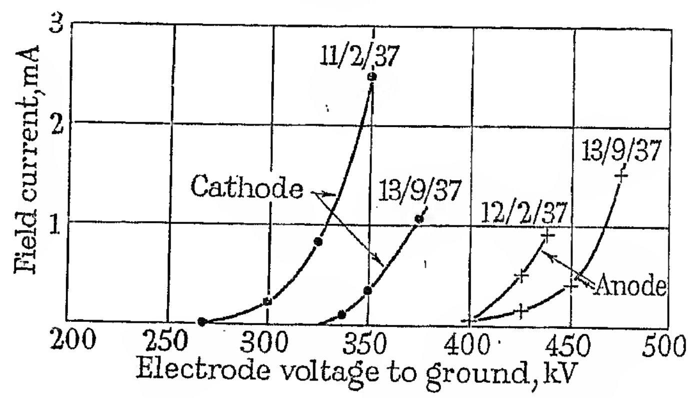


Fig. 21.—Variation of field currents with electrode voltage and polarity.

The size of the focal spot on the target varied with the distribution of the potential in the tube. Increasing the cathode voltage effectively increased the size, while increasing the anode voltage effectively decreased the

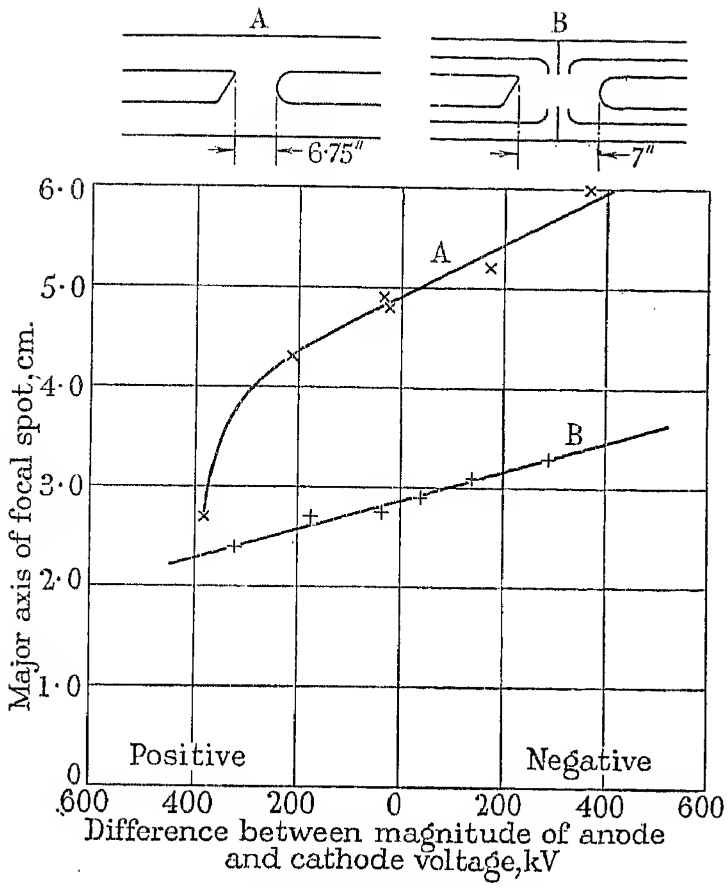


Fig. 22.—Size of focal spot as a function of asymmetry of voltage on anode and cathode.

The insets show the tube in 2 stages of construction:—
A. Without mid-potential shields.
B. With shield electrodes round the cathode and anode.

size. This would be expected from a study of the alteration of the distribution of the lines of force, which control the direction of the electron stream, and it would be expected that the focal-spot size would vary with the difference between the magnitudes of the anode and cathode voltages. This fact is proved by the curves in Fig. 22. The sudden bend on the positive side of curve A is probably due to the effect of the nose of the target at high positive potentials. With the addition of the central earthed electrode and the hemispherical ends to the mid-potential electrodes there was a marked reduction of the size of the focal spot, as would be expected, but the relationship between the size of the spot and the potentials still held (see Fig. 22, curve B). With + 400 kV and − 300 kV on the tube before modification, the average loading on the gold of the target was 70 watt/cm²/kW.

It is interesting to note that the saturation voltage on the tube is practically dependent on the voltage on the cathode. Alteration of the voltage on the anode had little effect, particularly after the tube had been modified. This is due to the fact that the extraction of electrons from the filament inside the cathode focusing hood is caused by the potential gradient at the cathode nose, which gradient is only appreciable when the cathode is energized.

(e) Efficacy of Lead and Barium Protection

The nature of the X-ray protective measures has already been described. Measurements of the X-ray

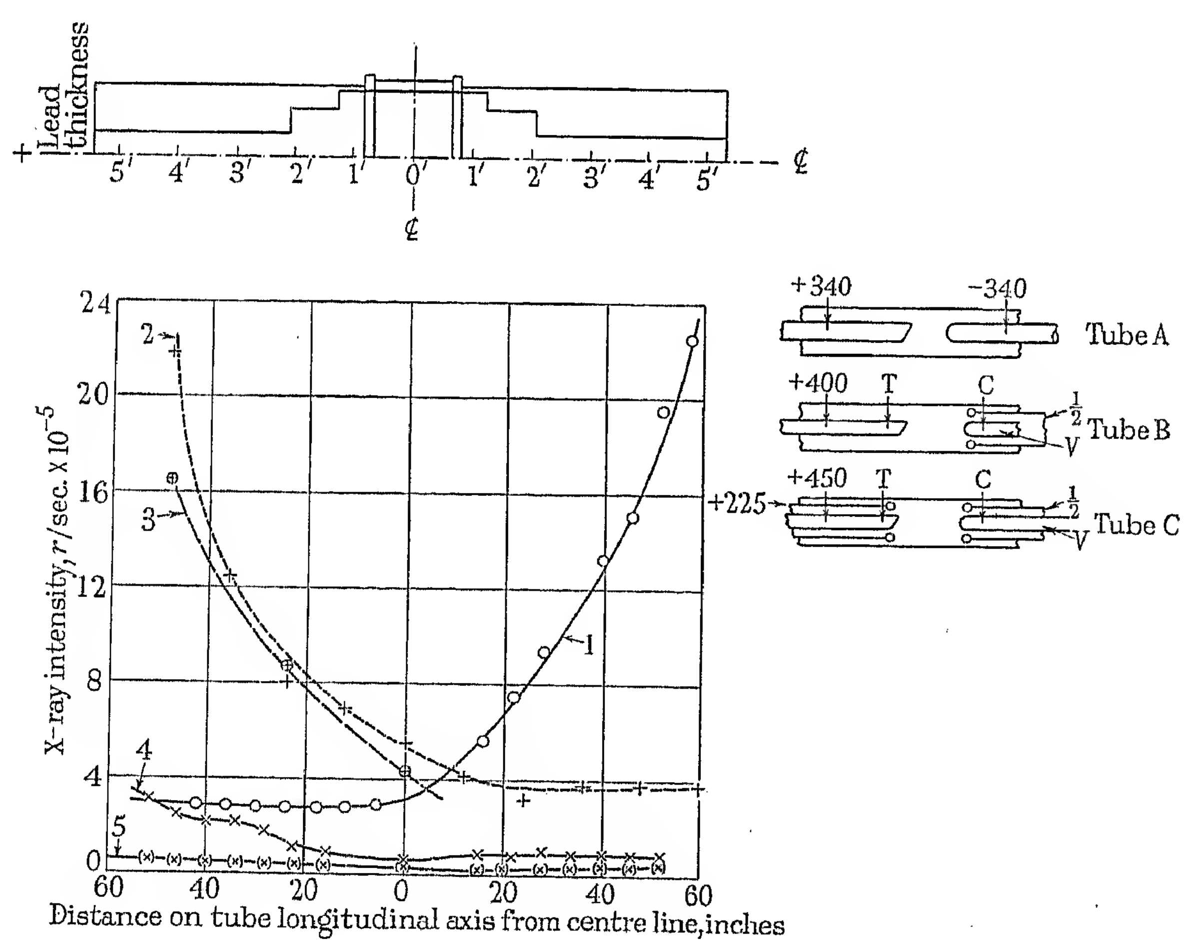


Fig. 23.

The top inset is a diagrammatic representation of the thickness of lead around the tube, corresponding to the abscissae of the curves.

The insets on the right show the tube in its various stages of construction:—
A. Without mid-potential shield electrodes.
B. With a shield electrode round the cathode.
C. With shield electrodes round the cathode and anode.

Curve 1. Tube A. + 340 kV − 340 kV, 3 mA.
„ 2. Tube B. + 400 kV − 400 kV, 3·6 mA.
„ 3. Tube B. + 400 kV − 200 kV, 3·6 mA.
„ 4. Tube C. + 450 kV − 400 kV, 4·0 mA.
„ 5. Tube C. + 450 kV − 100 kV, 4·0 mA.

leakage from the tube were made parallel to the tube axis and 2 in. from the applicator cylinder with a small search electroscope calibrated against radium. Some results are given in Fig. 23.

The leakage at each end of the tube increased rapidly with voltage once the threshold voltage for field currents was exceeded at either electrode, so apparently some of the leakage was due to X-rays generated by field currents. The addition of the mid-potential shield electrodes effectively removed this leakage radiation; not only was the field current reduced in magnitude but the X-rays generated by it were generated at lower voltage. The improvement due to this is shown in curves 1, 2, and 4, of Fig. 23. There still remained an X-ray leakage dependent on voltage and more intense at the positive end of the tube (see curves 4 and 5). It was observed in 1937 by Corrigan and Cassen* that the X-ray beam in the direction of the cathode beam is much more penetrating and intense than that at right angles to the beam, and it is suggested that, since the lead protection is symmetrical about the axis of the tube, the increase of leakage shown in curve 4 is due to this effect.

Outside the treatment room and the generator rooms no X-ray leakage could be detected with a Geiger counter.

(5) COMPARISON WITH OTHER HIGH-VOLTAGE TUBES

Most other tubes up to the present time have been energized with either pulsating or alternating current. The authors have had considerable experience with tubes operating on alternating current as well as direct current and they are confident that much higher voltages can be applied to the type of tube they have described, when operating on direct current. The flashover potential of the tube insulators is higher on direct current and the tubes appear to operate with greater stability. With this design of tube the capacitance current would be high on alternating current and introduce further complication. No trouble has been experienced with targets, provided that the focal spot has been of reasonable size, which is permissible, since for therapy there is no necessity for a point source of radiation.

The degrees of freedom of movement between the patient and the emergent beam are greater than those available on other extra-high-voltage tubes, although some of the other designs could be adapted to give the same freedom. The required freedom is one of the features which has governed the design of the tube to a great extent, and the authors are indebted to the Hospital Authorities for their repeated assistance. The X-ray protection on the tube is believed to be more complete than on any of the other extra-high-voltage tubes.

The intensity of the emergent beam is not easily compared with that from other tubes, owing to lack of published data and to difficulties encountered in the interpretation of results unless quoted under identical conditions, which are practically impossible to obtain on account of the various types of tube wall employed.

There is no reason to believe that the output should differ from that of other types of tubes operating on direct current, provided that the X-ray beam is brought out at the same angle to the electron beam, but no other published intensities are as high as those quoted in the paper. This is not surprising, as the grid control which improves the efficiency of tubes operating on alternating current or pulsating voltage is only applied to one or two of the other tubes. In the case of tubes having transmission-type targets, as already mentioned the intensity of the beam emerging in the same direction as the electron beam is so much higher than in other directions that future tubes will no doubt be designed to make full use of this recently discovered fact. Another interesting and valuable development recently announced by the General Electric Co. is the combined transformer and X-ray tube built into a steel tank filled with CCl_2F_2 gas

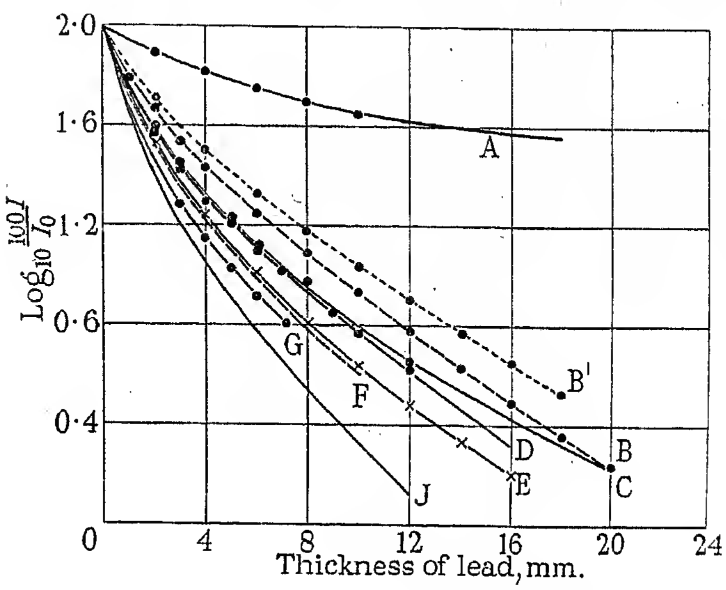


Fig. 24.—Comparative curves for absorption in lead.

Type	*Voltage* (kV)	*Location*	*Filter (mm.)*
A. Gamma-rays from radium			0·5 Pt
B. D.C. generator	900	Bart's	4·5 Fe, 1·5 Al
B′. ,, ,,	1 000	,,	4·1 Fe, 2·5 Al
C. H.F. generator	850 (estimated)	San Francisco	0·5 Cu, 3·2 Fe
D. Villard pulsating-voltage generator, biased grid	800	Seattle	3·0 brass, 10·0 water, 2·0 Al, 4·0 celluloid
E. A.C. generator, biased grid	750	Pasadena	5·0 Fe
F. D.C. generator	700	Bart's	3·2 Fe, 1·5 Al
G. D.C. generator	650	Lincoln Nebraska	3·0 Fe, 10·0 water, 3·0 Al
J. Induction coil (transmission target)	700	Memorial N.Y.	0·15 W, 3·0 Cu, 3·7 water, 1·0 brass

at a pressure of several atmospheres; this offers great attractions of economy of space, but sufficient details are not yet available on which to base a considered view.

The absorption in lead of X-rays from the 1 000-kV tube is given in Fig. 24, together with published data of other high-voltage tubes. Unfortunately direct comparison is not possible, owing to the wide variations of filtration, but it will be seen that the tubes operating on direct current give the hardest beam for the same voltage.

(6) CONCLUSIONS

The tube has been in operation for over 2 years, during which time it has been energized for 2 800 hours. It has proved reliable in service, and at no time has a vacuum leak developed in any of the vacuum gear during opera-

* See Reference (25).

tion, except when the target punctured. Even this only held up treatments for 2 days.

The design embodying the short path between the cathode and the target has proved to be satisfactory up to the voltage named and has ensured a fixed focal spot and a steady X-ray output. With the addition of the various hoods and mid-potential cylindrical shields the tube has resolved itself into a small central section containing the multiple acceleration electrodes for the electron beam and two long leads bringing the necessary supplies to the required positions. The absence of any electrotechnical restriction to the length of the tube has enabled the Hospital Authorities to construct a spacious and bright treatment room, conducive to the treatment of patients under pleasant conditions.

Though the tube is primarily designed for therapy it can of course be used for industrial radiography and then possesses the advantages of gamma-rays with the added one of high intensity. When a radiograph of a composite structure including thick and thin material is required, the shorter-wavelength rays are more suitable than the long in that the scattered radiation is much softer than the original beam and so is easily absorbed. Therefore the scattered rays from the thick parts do not completely obliterate the X-ray shadow of the thin parts. The difference between 200-kV X-rays and the gamma-rays in this respect is well shown in a radiograph of a microscope in Mr. Pullin's book " Engineering Radiography."* To demonstrate the capabilities of the high-voltage tube, a microscope radiograph is shown in Fig. 25 (see Plate 3) which should be compared with the radiograph taken by radium (shown in Fig. 30*b* of the above-mentioned book): the X-ray photograph was taken in 2 minutes at a distance of 10 ft. from the tube operating at 700 kV, 3 mA, whereas the gamma-ray photograph was taken in 44 hours at a distance of 7 ft. from a source of 76 mg. of radium.

(7) ACKNOWLEDGMENTS

The authors have been fortunate in being able to draw upon the wealth of experience of many colleagues in the physics and engineering sections of the Research Department of Metropolitan-Vickers Co., and to them they wish to express their indebtedness; especially to Messrs. A. Beetlestone, P. P. Starling, J. E. Taylor, and R. S. Quick. Their thanks are due also to Dr. A. P. M. Fleming, C.B.E., Director and Manager of the Research and Education Departments, Metropolitan-Vickers Electrical Co., Ltd.; and to Dr. Donaldson, Dr. Finzi, Prof. Hopwood, Dr. Levitt, Dr. Phillips, and the late Dr. Canti, of the St. Bartholomew's Hospital Cancer Department, for their constant advice and encouragement in regard to the development and installation of this apparatus, and for permission to publish this paper. The electrical measurements made on the X-ray tube have all been taken by one of the authors (G. S. I.) with the permission of the Hospital Authorities, as it was impracticable to test the tube first in the laboratories of the Metropolitan-Vickers Co.; and the physical X-ray measurements have been made under the general direction of the Cancer Committee.

* G. Bell & Sons, 1934.

REFERENCES

(1) W. D. Coolidge: *Science*, 1925, vol. 62, p. 441.
(2) W. D. Coolidge: *Journal of the Franklin Institute*, 1926, vol. 202, p. 693.
(3) C. R. Burch: *Proceedings of the Royal Society*, 1929, vol. 123, p. 271.
(4) W. D. Coolidge: *General Electric Review*, 1928, vol. 31, p. 184.
(5) W. D. Coolidge, L. E. Dempster, and H. E. Tanis: *American Journal of Roentgenology*, 1932, vol. 27, p. 405.
(6) J. E. Rose and D. H. Loughridge: *Radiology*, 1936, vol. 27, p. 656.
(7) C. C. Lauritsen and R. D. Bennett: *Physical Review*, 1928, vol. 32, p. 850.
(8) T. R. Folsom: *Radiology*, 1936, vol. 27, p. 684.
(9) D. H. Sloan, R. S. Stone, M. S. Livingston, and M. A. Chaffee: *ibid.*, 1935, vol. 24, pp. 153 and 298.
(10) R. S. Stone and P. C. Aerbersold: *ibid.*, 1937, vol. 29, p. 296.
(11) J. D. Cockcroft and E. T. S. Walton: *Proceedings of the Royal Society*, 1932, vol. 136, p. 619.
(12) M. A. Tuve, L. R. Hafstad, and O. Dahl: *Physical Review*, 1935, vol. 48, p. 315.
(13) J. G. Trump and R. J. van de Graaff: *Journal of Applied Physics*, 1937, vol. 8, p. 602.
(14) A. Brasch and F. Lange: *Zeitschrift für Physik*, 1931, vol. 70, p. 10.
(15) A. Bowers and J. H. van der Tuuk: *British Journal of Radiology*, 1936, vol. 9, p. 431.
(16) T. E. Allibone, F. E. Bancroft, A. Beetlestone, and G. S. Innes: *ibid.*, 1934, vol. 74, p. 65.
(17) F. E. Bancroft: *ibid.*, 1937, vol. 116, p. 630.
(18) C. R. Burch and C. Sykes: *Journal I.E.E.*, 1935, vol. 77, p. 129.
(19) J. D. Cockcroft and E. T. S. Walton: *Proceedings of the Royal Society*, 1932, vol. 136, p. 619.
(20) W. V. Mayneord: *British Journal of Radiology*, 1933, vol. 6, p. 598.
(21) R. Phillips and G. S. Innes: *ibid.*, 1938, vol. 11, p. 498.
(22) H. M. Parker and J. Honeyburne: *ibid.*, 1935, vol. 8, p. 684.
(23) W. V. Mayneord and J. E. Roberts: *ibid.*, 1935, vol. 8, p. 341.
(24) H. W. Anderson: *Electrical Engineering*, 1935, vol. 54, p. 1315.
(25) K. E. Corrigan and B. Cassen: *American Journal of Roentgenology*, 1937, vol. 37, p. 811.

[The discussion on this paper will be found on page 674.]

DISCUSSION BEFORE THE INSTITUTION, 13TH APRIL, 1939

Prof. E. W. Marchant: The paper is of great interest to me because it was just about 40 years ago that I first made some experiments with X-rays, soon after Röntgen's discovery. The greatest difficulty we had to contend with was that of keeping the character of the X-rays constant during the tests that were being made of the absorption produced by various metallic salts. We found that the absorption was dependent on the atomic weights of the constituents of the substances we were examining. We employed a continuously evacuated tube using a vacuum pump devised by the late Lord Blythswood, which was able to maintain a vacuum in the neighbourhood of 0·001 mm. of mercury.

It is now known that the sphere-gap does not give an accurate measure of voltage unless the frequency of the voltage is known. With high frequencies the electric strength of air falls; at a frequency of 1 000 kc./sec. it is reduced by 10 %, whereas, with impulsive voltages, the breakdown voltage increases. To those of us who have been trying to establish a consistent system of units it seems a little unfortunate that the unit of X-ray dosage should be defined in terms of the amount of ionization produced in a cubic centimetre of air which will give 1 electrostatic unit of charge. I should much prefer to see the unit defined as that which would give in 1 cubic metre of air a charge of 1/3000 coulomb, or in 1 cubic centimetre of air a charge of 1/3000 microcoulomb.

Dr. J. D. Cockcroft: The main claim that I have to take part in this discussion arises from the fact that I worked in the same room in the Cavendish Laboratory as Dr. Allibone when he started the work which ultimately led to this paper. At that time, in 1925, the work of Dr. Coolidge had created a great deal of interest in the production of high-speed electrons, and Lord Rutherford in particular was very much interested in having methods developed for making atomic particles move as fast as possible. The opportunity for developing this work in England was provided by the foresight of our President, Dr. Fleming, who encouraged Dr. Allibone to take 2–3 years off from industry in order to start work in the X-ray field.

I well remember the arrival of Dr. Allibone in Cambridge, equipped with a large Tesla coil which produced sparks twice as long as any which had ever before been seen in the Cavendish Laboratory. It was furthermore equipped with a very fierce rotating spark-gap in the primary circuit which disturbed all the experiments and wireless sets in the neighbourhood. Before Dr. Allibone left Cambridge he had discovered for himself the main principles in the design of high-voltage apparatus, and since that date those principles have been of the greatest importance to us in Cambridge in the development of our work on atomic transmutation. As we have seen, since Dr. Allibone left Cambridge he has been able to translate those principles into engineering design. That is shown by the 250 000-volt tubes which are now installed in so many hospitals and by the tube described in this paper. It seems to me that this particular design has now been pushed as far as it is practicable to go, and that if higher voltages are desired in the future it will be necessary to proceed to some design of the type in which both the generator and the high-voltage tubes are installed in a large earthed tank surrounded by gas at a high pressure. Possibly, however, there will be found indirect means of producing high-voltage X-rays.

So far as physicists can see, there is no particular virtue in higher voltages. They make the electrons produced in the tissues move faster, but there would seem to be no special reason why that should have any preferential effect. There are, however, advantages of increased efficiency and increased penetration associated with higher voltages, and one would have liked to have seen a comparison between the penetration of radium radiation and that of these rays produced by the authors' tube working at its full voltage.

I am interested in one technical feature of the authors' tube, namely the extremely low field strength at which auto-electronic emission sets in. Usually one does not expect to get trouble from this phenomenon till field strengths of the order of 100 kV per cm. are reached. The difference here may be a consequence of the fact that the surfaces in this tube are very much larger than are met with in most high-voltage tubes.

Dr. R. Phillips: I have had the privilege of using this apparatus at St. Bartholomew's for nearly 2 years, during which time over 1 500 individual treatments have been given. First of all, I should like to emphasize its absolute dependability—during this 2-year period I have only twice been prevented from giving treatment as planned. Once the target punctured, and on the second occasion a transformer coil burnt out. Another feature of the tube is its flexibility and controllability. A given set of conditions can be maintained absolutely constantly week in and week out, and there is never any doubt as to the amount of radiation which is being administered. A further point is the simplicity of the apparatus; it is quite foolproof.

The increasing use of technical apparatus and instruments of precision in medicine might lead one to think that medicine is a matter of pushing the right button or turning on the right tap, but I would emphasize that this is not the case. Radiotherapy, in spite of using these very precise instruments, has not become a mechanical science; it remains a part of the art of medicine, and each patient is an individual to be treated primarily from clinical knowledge, which is based on experience and observation.

The installation of the 1 000 000-volt X-ray tube at St. Bartholomew's Hospital may well mark an important step forward in the campaign against cancer.

Mr. W. E. Schall: Near the beginning of the paper it is stated that one of the main purposes which the installation may be called upon to serve is to find out whether there is any difference in clinical effect as between one wavelength and another. Until comparatively recently the many workers who have searched for such a difference in clinical effect have failed to find it, but of course they were only able to go up to 200 000 or 250 000 volts, and later to 400 000 volts. It will therefore be extremely interesting to learn as the years go by (this sort of thing can only be determined after 3–5 years) whether there really is a difference in the clinical effect due to 1 000 000-volt radiation as compared with radiation produced by lower voltages.

I must confess that I wonder whether such a difference would not set in at voltages above 1 000 000 volts rather

than below. We already attack the K ring of electrons in atoms with voltages rather lower than 100 000 volts, and to obtain much more striking effects I imagine it would be necessary to attack the nucleus of the atom, which is what would be done with voltages higher than 1 000 000 volts. The 1 000 000-volt plant at St. Bartholomew's Hospital will, I am sure, contribute a great deal towards the solution of that problem.

Dr. W. V. Mayneord: Having had an opportunity of seeing a number of other high-voltage plants, particularly in the United States, I may remark that the plant described in the paper seems superior to any other high-voltage equipment I have seen. Some of the pioneer high-voltage installations have little flexibility compared with this, while their constancy of output is not comparable with that of the St. Bartholomew's Hospital apparatus. It seems to me that a number of the pioneers of high-voltage X-ray plants have reached their high voltages by sacrificing the flexibility and shockproof quality of the apparatus. The authors, on the other hand, have succeeded in retaining important clinical elements, such as accuracy of dosage and application to the patient, while at the same time reaching potentials of a very high order.

I should like to know their views on such plants as van der Graaff generators, which are certainly simple and relatively cheap initially, although of limited output.

As regards the relative merits of the radiations derived from high-voltage X-ray plants and from radium, our experience of the use of fairly large radium packs for some years at the Royal Cancer Hospital shows that the penetration of the radiation from radium is very different from that of the radiation obtained from the St. Bartholomew's X-ray plant. With a 5-gramme unit of radium the percentage depth dose, i.e. the ratio of the dose 10 cm. deep to the dose on the surface, is about 16 %, as compared with 60 % to 65 % for the authors' equipment; so that, for a given dose on the skin of the patient, 10 cm. deep with this plant it is possible to obtain something like $3\frac{1}{2}$ times as much radiation as with a radium " pack " used under what are practically the best modern conditions. This is a very peculiar result, in view of the real penetration of gamma-rays as compared with X-rays, but of course it arises from the fact that the output of the authors' apparatus is so enormous that the origin of the radiation can be taken a long way away.

There are a number of small points in connection with the measurement of the radiation about which I should like to ask. By how much does the intensity of the radiation vary as the angle of the port is varied with respect to the target? As I understand it, the target is kept fixed. Unfortunately the authors have not been able to take account of the greater penetration and the greater amount of radiation which is received at small angles to the cathode rather than at right angles to it, but doubtless in future designs that will be considered.

I was surprised to learn that at 700 kV an aluminium-wall chamber behaves nearly as an air-wall chamber, particularly in view of the fact that even for gamma-rays there are differences between aluminium-wall and air-wall chambers.

As to the effects of even higher voltages, I should like to know whether there is any appreciable depth-dose change as between 700 000 and 1 000 000 volts. Theoretically one would expect very little change indeed for large fields. For small fields one would expect a rise of depth dose with voltage.

I notice that the authors found the relation between the X-ray output and the voltage to be a simple power law. This result is not in accordance with the results obtained by other workers, and I should be glad if we could have more information about it.

Dr. N. S. Finzi: The object of the work which is being carried out with the St. Bartholomew's X-ray plant is twofold: first, to discover whether rays generated at 1 million volts have different biological effects from rays produced at lower voltages; second, to see whether, with this higher voltage and higher intensity, we can get better results on account of physical characteristics.

I also have inspected most of the high-voltage X-ray plants in the United States, and I did not see one which worked as steadily as ours works now at 1 million volts. It works with absolute steadiness at this voltage giving an output which varies by not more than 1 %.

As we can only treat a limited number of patients every year, it will be a long time before we are able to assess the results of the experiments. Five years have to elapse from the time the patient has been treated before it is possible to say whether the treatment is a success.

I should like to point out that the design of the tube might have been very different had not the medical staff of the Hospital insisted that certain conditions must be fulfilled, conditions which were difficult, but which in practice have proved what a flexible apparatus this is.

Dr. Mayneord has mentioned the question of the percentage depth dose; between 700 000 and 1 000 000 volts with small fields the percentage depth dose will improve, and for medical purposes small fields are often extremely necessary. Big fields tend to be very dangerous, and do not have the desired effect in many types of case. With the particular type of case for which we think the million-volt apparatus is likely to be effective we shall get a very much bigger depth dose by using 1 000 000 volts than 700 000 volts, at which we had worked until recently.

Dr. L. H. Gray: I think it is hardly to be expected that the secondary electrons produced by high-voltage radiation would produce a marked difference in biological response by virtue of their greater energy. There is, however, another way in which high-voltage radiation can differ from 200-kV radiation. The biological effect depends on the electrons which reach the cell from surrounding material, and if that surrounding material happens to contain elements higher in atomic number than oxygen, even only as high as calcium (in bone) or sulphur (in skin), then the amount of secondary electronic energy to which the cell is subjected is considerably greater in the case of the 200-kV radiation than in the case of an equal dose of radiation from the 1 000-kV tube. It is at present, however, uncertain whether the proportion of calcium, sulphur, and similar elements in the tissues is sufficient to produce any marked effect. There is some evidence that the 1 000-kV radiation will pass through skin and do less damage to it than 200-kV radiation, although both will do the same amount of damage to the tumour cell.

[The authors' reply to this discussion will be found on page 678.]

NORTH-EASTERN CENTRE, AT NEWCASTLE, 27TH MARCH, 1939

Prof. H. L. Riley: In the attack upon the problem of cancer, X-rays are proving of service in two fields, namely X-ray therapy and X-ray crystallography. In the latter field X-rays are employed for the determination of the atomic structure of solid matter, making use of diffraction effects which occur when a beam of X-rays is incident upon an ordered structure of atoms. The new weapon which has thus been placed in the hands of the chemist has already provided a much deeper insight into the nature of solid matter than had previously been possible. The use of X-ray crystallography has already proved of considerable service in the study of the structure of biochemical compounds in general and of carcinogenic and related substances in particular. The X-ray crystallographer has also benefited indirectly from the research which has been carried out on the design and structure of the tubes used for X-ray therapy. From my own experience of a 100-kV continuously evacuated tube I can strongly recommend it as a thoroughly reliable piece of laboratory apparatus.

Dr. S. F. Evans: It was once thought that with very high-voltage X-ray tubes a greater selective destructive action was produced in cancer tissue than with tubes operating at lower voltages, but this idea has now been abandoned. A recent development in X-ray therapy is the Chaoul tube, which operates at a comparatively low voltage of the order of 60 kV. In suitable cases this appears to give the same degree of selective action as the more familiar 200-kV tube. It follows, therefore, that the advantage of the 1 000-kV tube lies in the increased depth dose. This is due to two factors: the high intensity enables the patient to be placed at a greater distance from the tube, and hence reduces the effect of the operation of the inverse square law; and secondly, the increased penetration reduces the absorption of radiation in the superficial tissues. I should be glad to know how the percentage depth dose obtained with the 1 000-kV tube compares with that obtained with a 200-kV tube under normal working conditions.

Dr. C. J. Thurgar: My interest in the paper is largely concerned with the question: What advantage will the authors' tube give over present methods in the treatment of cancer, and at what cost? I am sure that the engineering knowledge gained has already justified the enterprise, but I have yet to be convinced that the very high voltage will prove worth while from a medical point of view. I hope that it will, and shall await with interest the purely clinical results.

Prof. James Dickinson: The careful design of the water system for the cooling of the target may appear unnecessarily complicated, but the loading on the gold of the target is high. I remember that in July, 1927, when I was at the Schenectady research laboratories of the General Electric Company (U.S.A.), experiments were being carried out with a cascade vacuum tube having an operating voltage of 900 kV, which was applied in three stages. The distance travelled by the electrons before emerging from a tungsten window at the end of the third tube was 10–12 ft. On emerging, the electrons streamed many feet into the room, and the ionization effects were very remarkable. I can therefore well imagine that in the authors' tube there will be a large concentration of energy at the focal spot on the target, much of which will be transformed into heat.

It is evident from Fig. 5 that the emergent beam traverses the ionization chamber before passing through the aperture in the lead diaphragm. Thus more rays thread the ionization chamber than traverse the applicator portal. Would not the daily control figure be more accurately determined if G were placed between K and L, so as to provide a check upon the separate measurement for X-ray dosage?

The paper makes no mention of the efficiency of operation of this high-voltage tube. I should be grateful if the authors would provide the following information: (*a*) A definition (or definitions) of efficiency in connection with this type of apparatus. (*b*) The mode of calculating the efficiency of transfer, i.e. from the transformer primary to high-voltage direct current. (*c*) The way in which the voltage-change during the charging period is predetermined. How far does theory agree with practice in the case of percentage fluctuation corresponding to any given load current and voltage? (*d*) How is the overall efficiency calculated? What is the value given by the experimental determination of overall efficiency?

[The authors' reply to this discussion will be found on page 678.]

NORTH-WESTERN CENTRE, AT MANCHESTER, 18TH APRIL, 1939

Prof. Willis Jackson: We must all hope that the use of the X-ray tube described in the paper will assist very appreciably the progress of biological research, and the search for an understanding of that intangible something which distinguishes animate from inanimate matter.

The point in the paper which attracts my attention most is the surprisingly low voltage-gradients at which field currents become troublesome—about 60 kV per cm. at the cathode surface and 20 kV per cm. on the inside surface of the earthed cylinder opposite the anode. If the degree of vacuum within the central portion of the tube is correctly 10^{-4} mm. as stated, the mean free path of the gas molecules (about 60 cm.) is substantially greater than the distance between these electrode surfaces; and it seems unlikely that the field currents can result from gaseous ionization either directly or from the generation of secondary electrons by ionic bombardment of the electrodes. It appears more likely, as the authors suggest, that they arise from auto-electronic emission, and yet one has come to think in terms of voltage gradients of not less than 10^6 volts per cm. as necessary for this occurrence. The possibility would certainly be increased appreciably by incomplete degassing of the metal parts, but hardly, one is inclined to feel, by a factor of 50. The fact that rubbing the cathode surface with emery paper increased the field current only twofold, suggests that the surface is already so rough that there exist local surface gradients considerably in excess of the

figures given. Since these working gradients are much lower than those employed in the 250-kV X-ray tubes, it would be interesting to know how the finish of the two sets of parts compares.

The transformation of the originally conceived tube with single-stage acceleration into one with multiple acceleration has provided an interesting contrast in design with the multi-stage tube of American origin mentioned in the paper.

I should like to know whether the authors are satisfied that the method adopted for measuring the X-ray output is a completely reliable criterion of dosage taken over the whole range of operating voltages envisaged. In the case of small tubes it is usual to specify that the absorption in the ionization chamber must be nearly complete, because of the fact that the ionization produced is not independent of the X-ray wavelength. The justification for the method adopted here lies, presumably, in the extremely high average frequency of the X-rays generated.

Mr. F. R. Perry: In Fig. 1 of the paper a comparison is given between the X-ray wavelength expressed in kilovolts for a tube operating at 1 000 kV and for the gamma-rays from Ra-B and Ra-C. While the radium shows a high intensity of gamma-rays at 600 kV, I note that an intensity of about one-third that amount is shown for gamma-rays of about 1 800 kV. These shorter-wave-length rays will have an enhanced penetrating power, and at even short distances from the radium source this higher penetrating power may offset the lower intensity; so that one might expect that, in radium treatment, the gamma-rays at 1 800 kV would be nearly as important as those at 600 kV. If this view is correct it would appear that higher-voltage X-ray tubes might be useful. For example, the most intense X-rays given by a 1 000-kV tube are apparently those having a wavelength of 600–700 kV. It would appear, therefore, that to produce a reasonable intensity of X-rays of 1 800-kV wavelength an X-ray tube working at 2·5–3 million volts would be required. In view of the authors' remarks on page 658 about finding an optimum voltage for treatment between 300 and 1 000 kV, it would be of interest to learn whether sufficient medical research has been carried out with the tube operating at various voltages to determine whether the optimum voltage will in fact lie between the limits suggested or whether even higher-voltage X-rays might not prove to be required. Since the authors have successfully experimented with intermediate potential electrodes in the present tube, it would appear that this principle could be further extended to deal with higher-voltage tubes for both the internal voltage distribution between electrodes and the insulation problems involved in the terminal bushings. The main difficulty about developing the present design for higher voltages would appear to be that of the large space required for the two d.c. generators at either end of the tube. It would be of interest to learn whether the authors have contemplated building tubes to operate at higher voltages than does the one described in the paper.

On page 665 it is stated that the high-voltage generators may be switched on provided the pressure in the X-ray tube is less than 10^{-4} mm. of mercury. Have the authors made any measurements of the gas pressure under working conditions, and, if so, does the degree of vacuum noticeably affect the performance of the tube if the gas pressure is below the upper limit given above? It would appear from the authors' remarks that the hardness of the vacuum would not appreciably affect the magnitude of the field currents obtained, although these field currents fall after a lengthy operation of the tube, presumably owing to prolonged degassing of the metal cylinder walls. Would the rate of improvement be materially increased if the normal working gas pressure was reduced from, say, 5×10^{-5} mm. to 5×10^{-6} mm., assuming this latter figure was possible in a tube of this size?

In Fig. 17 is given a series of curves showing how the X-ray intensity varies with the total tube voltage, when the anode voltage has a number of fixed values and the total cathode current is kept constant. Comparing these curves with Curve A of Fig. 16, it would be of interest to know the values of the anode and cathode voltages used in obtaining the results given in Fig. 16. It is presumed that these voltages were so adjusted as to give the maximum X-ray output in this case.

It is mentioned on page 660 that vapour condensation traps were fitted for experimental purposes; I should be interested to learn whether these have ever been used, and, if so, whether any noticeable improvement in the vacuum was thereby attained.

Miss M. C. Todd: The paper deals with some of the difficulties which the radiological side of the medical profession have to face when they wish to treat with X-ray tubes which work at voltages up to 1 million volts. The same difficulties really apply to all X-ray work at voltages of over 400 kV. The wavelength of the rays is very important; for example, for certain purposes radium has a real advantage over X-rays of wavelengths corresponding to 200–250 kV, which was all we previously had to work with. It may seem difficult to understand where that difference lies, because the effect on the tissues must be the effect of the radiation absorbed. This is measured with considerably difficulty, because when the ray strikes the patient, " back scatter " is at once obtained from the tissues of greater density. The question of " back scattering " is very important because the scattered rays are degraded (the Compton effect), and at present it is not known what is the actual biological effect of the action which takes place within the cell. This action must ultimately be due to absorption of the degraded radiation by atoms in the protoplasm. The difficulty is that we cannot examine the proteins of the cell at a living stage. To make it possible to examine them we have to kill, and study of the dead cell gives only limited information.

We have to rely on all sort of hypotheses to guide us in the treatment of the patient. One suggestion is that the absorption of the longer wavelengths in atoms of higher atomic weight than the carbon, oxygen, and hydrogen which constitute most living tissue, produces the biological anomalies which have been noted. For instance, it is suggested that the effect on the skin is due to the presence of sulphur, which is present in quite large quantities in the keratin produced by the cells. This possibly explains why short-wavelength radiation has less effect on the skin than long-wavelength radiation.

Another suggestion is that the presence of bone in the tissue makes a great deal of difference. In the treatment of cancer inside the mouth with 200-kV X-rays there is a very considerable absorption in the jawbone, whereas if radium is used the absorption in the bone is practically negligible. We want to work at a depth of 10 cm. within the body for many of the lesions we have to treat, and therefore it is obviously impossible to use radium, which can only be taken to a distance of 5 cm., a very poor proportional depth as compared with 60 cm.—the distance generally used between target and skin for X-rays.

Turning to the question of the apparatus, I was in the United States last year and saw some of the X-ray tubes produced over there. I do not think any of them are in advance of that described in this paper. The work which has been done in connection with the million-volt tube at St. Bartholomew's Hospital is pioneer work. Nowhere else in the world has such a stage of accuracy been reached in measuring the dosage actually received in the tissues from high-voltage radiation.

We are now having installed at the Christie Hospital, Manchester, a 500-kV apparatus which we hope will also be of service in scientific research. With this apparatus it is possible by heavy filtration and using longer distances to get quite a short wavelength and good penetration. Naturally under these circumstances we have to cut down our intensity, but that is not very important, because low intensity rather than high intensity is usually advocated as the best method of working.

Mr. J. F. Smee: It would be interesting, even to a layman like myself, to know whether doctors expect any striking results to accrue from the rise in voltage of X-ray tubes. Have they found that the higher-frequency radiation has a more markedly selective effect on healthy and unhealthy tissue?

Mr. C. Ryder: I should like to know whether the problem of focusing X-rays has been investigated. If it were possible to do this it would seem that a considerable saving in material could be made, since at present only a small fraction of the generated X-rays is usefully employed.

THE AUTHORS' REPLY TO THE DISCUSSIONS

Dr. T. E. Allibone and **Messrs. F. E. Bancroft** and **G. S. Innes** (*in reply*): We have been very gratified that a paper of rather restricted interest should have provoked such a useful discussion, and we are specially grateful for the contributions made by members of the medical profession and by physicists who normally do not contribute to the proceedings of The Institution. Their remarks have added considerably to the interest the paper has aroused in engineering circles.

With reference to points of design, it should be noted that this tube was designed long before the effect described by Messrs. Corrigan and Cassen was observed [Reference (25) of the paper]; so, as Dr. Mayneord points out, it is unfortunate that the X-ray beam has to be taken at right angles to the cathode beam, and not in the same direction. There is, however, no reason why a tube on similar lines should not be made with a transmission-type target and give the X-ray beam in the optimum direction.

The intensity varies as the angle of the port is varied with respect to the fixed target; exploration with a small ionization chamber shows a variation of 4 % from the perpendicular to the target to an angle of 55° to this perpendicular. In the large ionization chamber fitted to the tube the effect is more marked; it amounts to 10 % at 55° to the normal position, on account of the wide angle subtended by this chamber at the target, but the isodose curves for large field sizes show negligible trace of a diminution of X-ray intensity at the limiting positions of use of the tube.

The present design is probably limited to about 1 200 kV, but one could foresee a similar design comprising concentric cylinders and earthed target operating up to about 2 000 kV. Above that figure the pressure type of electrostatic belt generator has very great merits, especially as the currents required would only be of the order of, say, 1 mA, a figure easily supplied by a modest width of charged belt. To extend medical research further in the direction made possible by these tubes it would be advisable to aim at not less than 3 million volts for any subsequent tube, preferably 5 million volts; and for this, some compressed type of design seems to be essential. The concentric-cylinder design would also have to be abandoned in favour of the long-electron-path tube to avoid the formation of excessive field currents. It must be emphasized that the known advantage to be gained by increase of applied voltage to, say, 3 million volts is increased intensity—probably 50 to 100 times that available from this tube for the same current; this would permit of greatly increased filtration and therefore of greater penetrating power of the filtered beam. Further, treatment could be given at 150–200 cm. distance, when the inverse-square-law effect is negligible and thus Curve C of Fig. 18 would be brought much nearer to Curve B, if not above it. Other physical effects may or may not be discovered; as Dr. Gray indicates, some new facts about the effect of wavelength are already coming to light.

The merit of the air-insulated tube in comparison with the tube installed under oil or in a compressed-gas chamber lies in the accessibility of those parts of the tube which require periodical attention, and in our opinion it is only for tubes operating above, say, 1·5 or 2 million volts that the advantages of accessibility are outweighed by the disadvantage of the large space required for the air-insulated design.

In reply to Dr. Mayneord's query about the van der Graaff generator, we agree that this generator in its original form is delightfully simple and relatively cheap, but such a generator designed to give 6–7 mA (the tube which we described has already operated at 5–6 mA, and the generators will give more than this without serious voltage ripple) at 1 million volts would probably cost as much as the thermionic generators described in the paper, and would not give the steadiness of terminal voltage which is the feature of thermionic generators. Furthermore, if a van der Graaff generator is constructed to give, say, 7 mA at 10^6 volts and is then used

in conjunction with a tube taking a lower current, the only way of keeping the voltage from rising above the desired operating voltage is by dissipating the spare current in corona. The amount of ozone, noxious fumes, and dust precipitation created by this dissipation of, say, 3 kW, will be enormous. This seems to be an inherent weakness of the electrostatic generator.

As mentioned by several speakers, the incidence of field currents at such low gradients is surprising. Dr. Cockcroft supports our suggestion that this may be due to the large areas of surface stressed. Evidence of a similar nature is found in corona studies. If observations on the starting voltage of corona for a given conductor are made, the results are found to depend on the length of the conductor under observation, the geometry of the conductor and surrounding electrodes being unaltered: corona points may occur at very wide spacings, so for short conductors corona is not detectable until the voltage is appreciably higher than that which causes corona formation on long conductors. H. W. Anderson* has studied the effect of total voltage on breakdown due to field currents in a vacuum tube, and finds that the cathode gradient at which breakdown occurs between a sphere and a plane electrode *in vacuo* falls as the spacing is increased. Direct comparison with his results is not possible, as the largest inter-electrode spacing for which his results are given is 4 cm., for which the maximum operating cathode gradient is − 120 kV per cm. However, our results point in the same direction: with an inter-electrode spacing of 5·5 cm. a cathode gradient of − 60 kV per cm. is insufficient to cause instability, but with a spacing of 12·5 cm. the upper limit of operation corresponds to a cathode gradient of − 57 kV per cm. The positive-ion ionization which he postulates may therefore explain our results at the cathode end of the tube, but there seems to be no satisfactory explanation for the onset of field currents at extremely low cathode-gradients at the anode end of the tube.

In reply to Prof. Jackson, the surface finish of the electrodes in this tube is comparable with that in the 250-kV tubes.

In reply to Mr. Perry, we do not think that a reduction of the normal working gas pressure would materially increase the speed with which the tube attains a given degree of stability at any one voltage. One experiment with the vapour-condensation traps cooled with solid CO_2 was made at the time the field current/voltage curves were being taken, but there was no noticeable effect on the field current. As far as we have observed, the degree of vacuum does not influence the field currents or the performance of the tube, provided the pressure is lower than 10^{-4} mm. To reduce the normal working pressure from 5×10^{-5} to 5×10^{-6} mm. would require a pump of 10 times the existing speed: with this pump speed the gas liberated from the walls would be taken away faster, but it does not follow that the gas would be liberated any faster, since the liberation is greatly assisted by heat generated in occasional high-pressure discharges.

In further reply to Mr. Perry, concerning Figs. 16 and 17, it should be noted that in Fig. 16 the tube is operating without field currents and so the distribution of total voltage between cathode and anode ends is immaterial.

With regard to Prof. Marchant's remarks, we know the sphere-gap calibration on direct current as we have installed accurate resistance voltmeters, and we find that the difference between the d.c. calibration and the 50-cycle a.c. calibration is very small. With regard to the definition of the unit, the röntgen, it must be appreciated that this is beyond our control.

In reply to Dr. Mayneord's last three remarks about X-ray intensity, we now know that comparison of the calibration curve of the response of the aluminium-plate chamber with that of a thick-walled graphite thimble chamber shows the chamber to be in error by not more than 6 % at 700 kV. Earlier measurements indicated the difference to be even less than this. With the change in operating voltage from 700 kV to 1 000 kV no change in percentage depth dose has been observed at 1 m. F.S.D.* for large or small fields with the filtration given in Section 4 (*c*); but the intensity is sufficient to make it possible to operate at 1 m. instead of at 60 cm. F.S.D., so that, as observed from Fig. 18 (Curve C), the percentage change in percentage depth dose is 16 %. The variation of intensity with voltage is only roughly quoted as a $2\frac{1}{4}$ power law in Section 4 (*c*); it is deduced from Fig. 16, and intended as a working rule only. Clearly it varies with filtration, but the tube here described cannot be used with less filtration than 4·1 mm. Fe. We would refer Dr. Evans to Fig. 18 for a comparison of the percentage depth dose from a 250-kV tube with that from the tube operating at 700 kV: the differences are even greater for 200-kV and 1 000-kV operation. At 200 kV and 100 cm. F.S.D. (this distance would hardly ever be used, as intensities there would be too small) the depth dose at 10 cm. for medium field size (10 cm. × 10 cm.) would not exceed 38 %, and might only be 33 % at 40 cm. F.S.D., the beam being filtered by 2 mm. Cu; whereas at 1 000 kV, 100 cm. F.S.D. (this distance is now accepted as standard), the depth dose at 10 cm. for the same field size is 50 %, the beam being filtered by 4·1 mm. Fe, 2·0 mm. Pb, and 2·0 mm. Al.

In reply to Dr. Thurgar, the tube is equivalent in output to £8 000 000 of radium, but unfortunately this sum was not realized when the tube was sold! The figures for percentage depth dose given to Dr. Evans form one justification for the higher voltage; we too must wait patiently for purely clinical results to show whether the engineering enterprise has been justified by purely medical results. The question of wavelength *per se* should be tackled carefully in at least a few first-class research centres, and both we and the firm with which we are associated hope that this tube will enable British medical men to study and settle this problem.

In reply to Prof. Dickinson, it should be noted that as a correction factor has to be applied for various parameters, namely field size, filtration, and F.S.D., it is immaterial where the ionization chamber is placed: it was therefore placed in such a position that it never had to be moved when filters, applicators, etc., were interchanged. With regard to efficiencies, we did not give these figures prominence because there is so little that

* *Electrical Engineering*, 1935, vol. 54, p. 1315.

* F.S.D. = "Focal Skin Distance," referred to as F on page 668.

can be done to affect them. One of the most important features not referred to as an "efficiency" of X-ray production is the effective wavelength for a given crest voltage: this governs the percentage depth dose, the all-important feature. The effective wavelength is shortest when the mean voltage is equal to the crest voltage on the tube. For circuits of the type described in the paper this is never possible; the voltage ripple depends on the capacitances, frequency, and number of stages of the generator as given by Cockcroft in Reference (19). A general definition of electrical efficiency would be the ratio (kilowatts supplied to tube)/(kilowatts input, excluding vacuum-pump and filament-heating power). When the tube takes 4 mA at 1 000 kV (almost 4 kW, as the voltage ripple is small), the power input to the two transformers is 5·2 kW, i.e. 77 % efficiency. In comparing the plant with other types of generator, however, the pump and filament losses must be added (say 4 kW), giving an overall efficiency of 45 %. Reference (19) and another calculation by Vanoni* give the basis of calculation. The voltage-change during the charging period could be determined if the saturation voltage of the rectifier were known accurately, but we have not obtained reliable figures for it. Apart from this, the calculations quoted above give the voltage-change, and agreement with experiment is moderately good. We have experienced difficulty in getting reliable figures for voltage ripple because with a generator of such small power the very introduction of a load for d.c. voltage measurement, or a capacitance for a.c. voltage measurement, on an oscillograph upsets the results. It is hoped at a later date to make a fresh study of these values.

* *L'Elettrotecnica*, 1938, vol. 25, p. 766.

Plate

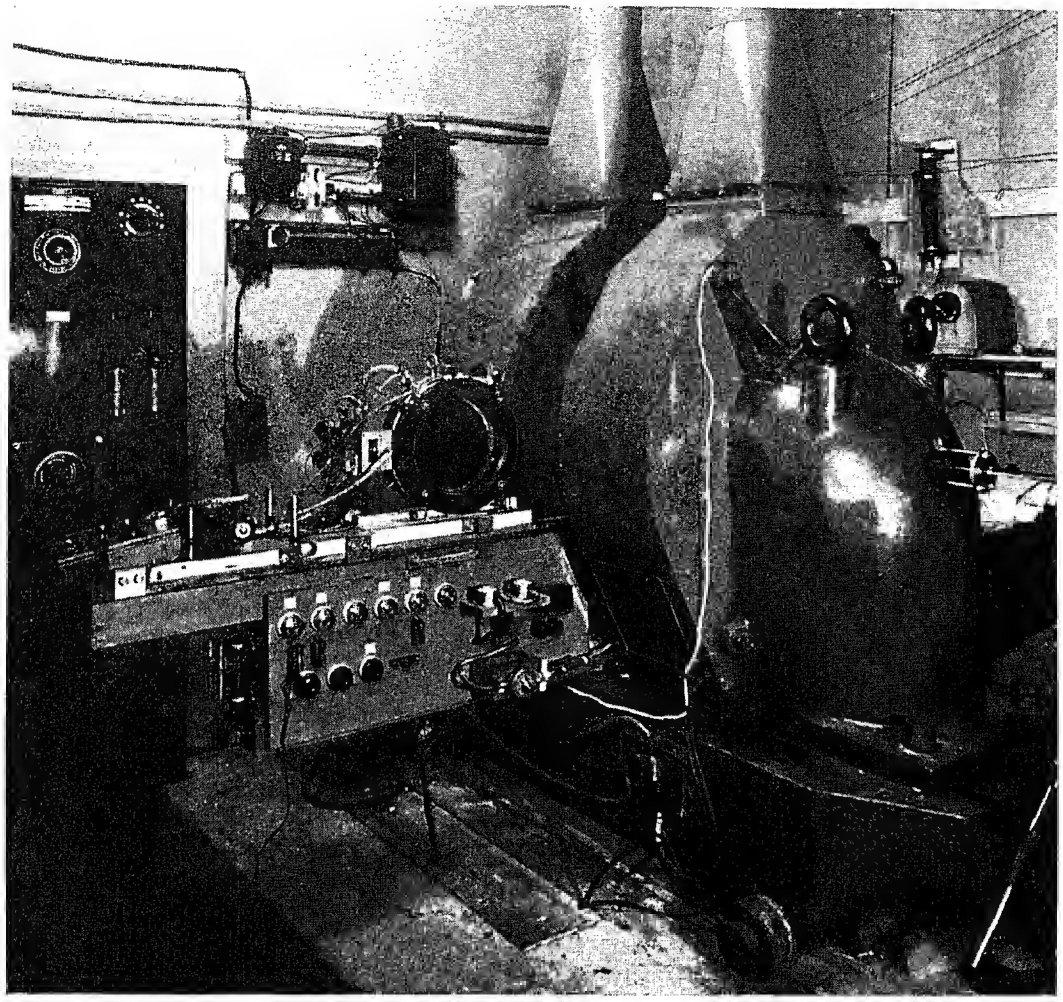


Fig. 2.—11-ton magnet (constructed by the Metropolitan-Vickers Electrical Co.), with cloud chamber.

The chamber is on rails, so that it can be slid in between the pole-pieces of the magnet. The ducts are for the air cooling of the magnet. The hole in the right-hand pole-piece is to take a camera, the end of which can be seen. This forms an alternative method of photography to that with the mirror shown in Fig. 1.

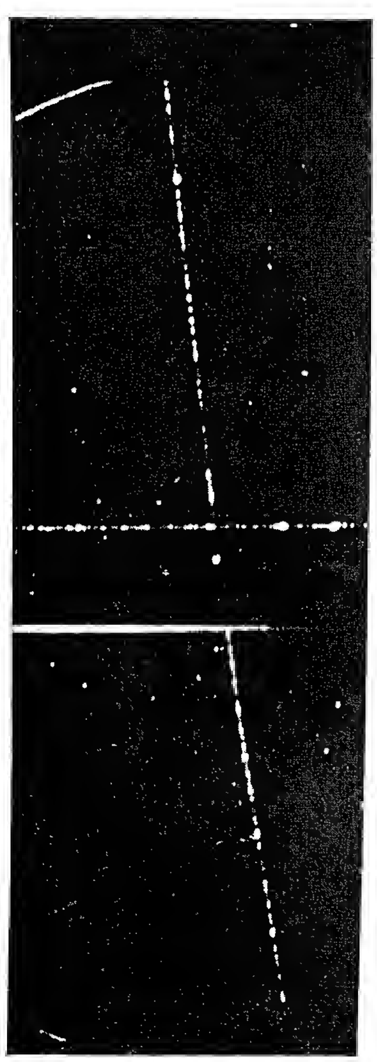


Fig. 3.—Photograph of mesotron traversing 2-cm. gold plate.

The mesotron has an energy of about 400 million electron volts, and loses only quite a little energy in the plate. Magnetic field = 10 000 gauss.

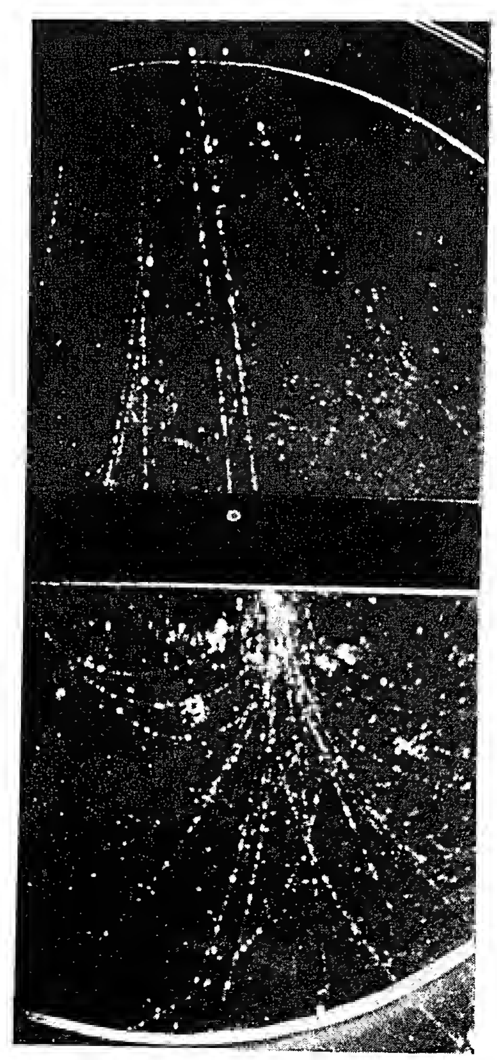


Fig. 4.—Photograph of cascade shower traversing 2-cm. gold plate.

The rays in the top half of the chamber are positive and negative electrons and have energies of from 50 to 400 million electron volts. The shower in the lower part of the chamber is presumably formed by energetic photons from the original upper shower which are absorbed by the gold plate.

THE THIRTIETH KELVIN LECTURE
"COSMIC RAYS"

By Professor P. M. S. BLACKETT, M.A., F.R.S.*

(*Lecture delivered before* The Institution, *27th April*, 1939.)

The study of what has now become the large subject of cosmic rays started near the beginning of this century with the discovery that air contained in a closed vessel at sea-level has a small residual ionization which could not be removed by the use of heavy lead absorbers, and which had therefore to be attributed to the existence of a radiation much more penetrating than that given out by radio-active material in the earth's crust. The crucial results which showed that the penetrating radiation was of extra-terrestrial origin came from the experiments in balloons which were made about 1911. These indicated that the ionization due to these rays increased as one went upwards, thus showing that the rays producing the ionization must be coming downwards and not upwards from the earth.

As a result of very many investigations, carried out in recent years all over the world, on mountains, in balloons and aeroplanes, underground in mines, and far under water, it is now known that the earth is being bombarded by atomic particles of surprisingly high energy. Whereas the most energetic particles, produced either naturally by radio-active rays or artifically in the laboratory by cyclotrons or high-voltage machines, are of the order of 10 million (10^7) electron volts, the average cosmic ray at sea level has an energy of the order of 1 000 million (10^9) electron volts, and a few probably reach an energy of 10^{15} electron volts or more. It is interesting to note that such very energetic atomic rays have an energy of macroscopic magnitude, e.g. a single 10^{15}-volt cosmic ray has an energy of 1 600 ergs.

Cosmic-ray research is carried out almost exclusively by four experimental methods: the ionization chamber; the tube counter; the cloud chamber, mostly in its counter-controlled form; and by the direct recording of heavily ionizing cosmic-ray particles by means of photographic emulsions. We shall be concerned here mainly with the third of these methods, the counter-controlled cloud chamber. This gives particularly clear pictures of the atomic processes involved in cosmic-ray phenomena. The method consists in arranging that the passage of a cosmic ray through two or more counters, arranged above and below a cloud chamber, shall actuate the mechanism of the chamber and so produce an expansion just after the passage of the ray. In this way the ions produced in the gas by the ray have water drops condensed on them before they have time to diffuse far from their place of formation on the track of the ray, and thus the tracks of the cosmic rays can easily be photographed. Using this method it is perfectly easy to set up an apparatus to record some special type of phenomenon, e.g. a large shower occurring on the average, say, only once an hour or even only once a day, and to arrange that the apparatus will wait until one of these rare events occurs, and will then ensure that the rare event will photograph itself.

Fig. 1 shows a type of cloud chamber specially developed for the accurate measurement of the energies of cosmic rays by their deflection in a magnetic field. It consists of a shallow glass-topped chamber A containing air at about 2 atmospheres pressure, with a movable floor or piston B kept tight by a rubber diaphragm C. The gas in the chamber is normally compressed by the piston being pushed forward on to the stops D, by means of a backing pressure of air in the space E. When a cosmic ray traverses the counters (not shown) and so the chamber, the impulse from the counters is utilized, by means of a relay mechanism, to open a valve closing the space behind the piston, and so lets the piston move to make the expansion. The time between the passage of the ray and the end of the expansion is made as small as possible, and is usually about 1/100 sec. Shortly after the end of the expansion, a bright flash is made to give a photograph of the tracks formed.

In order to determine the energy of the rays it is necessary to measure their curvature in a magnetic field. For this purpose the magnet shown in Fig. 2 (see Plate facing page 681) was constructed a few years ago. It is of very simple construction and is air-cooled. The pole-face diameter is 25 cm., and with a gap of 15 cm. it gives 10 000 gauss for an input of only 7 kW. The maximum power obtained with the existing cooling fan is about 30 kW, and the magnet then gives a field of 13 000 gauss with a 15-cm. gap.

With such a chamber and magnet it has proved possible to measure the energy of cosmic rays up to values of 2×10^{10} electron volts. This involves measuring very small curvatures, since in a field of 10 000 gauss the radius of curvature of a ray of this energy is as much as 70 m. Since the measurable length of the tracks is only some 20 cm., this curvature leads only to a very small angular deviation. Special optical methods have therefore been developed to make this measurement possible. Further, great care must be taken to ensure that the gas in the chamber before an expansion is at a constant temperature, otherwise gas movement occurs which seriously distorts the tracks. Fig. 3 (see Plate) shows the passage of a ray through a 2-cm. gold plate without any visible distortion at all. From photographs like this last it is possible to measure the energies of the rays on each side of the plate up to values

* The Physical Laboratories, The University, Manchester.

of 10^{10} electron volts, and so to determine the energy they lose in traversing the plate.

It is now known that cosmic rays can be divided into two main types: (1) absorbable rays and (2) penetrating rays. The former consists of positive and negative electrons and photons, and the latter of a new type of particle, intermediate in mass between electrons and protons. These new "mesotrons" have a mass of about 170 times the mass of an electron and occur equally with positive and negative charges. The particle giving the track shown in Fig. 3 is a mesotron. What makes these rays of special interest is that they are apparently unstable, i.e. they decay spontaneously, even in free space where there is no matter present, into electrons, and, so the theoretical physicists tell us, into neutrinos as well.

The behaviour of the soft or absorbable electronic component is now believed to be fairly well understood, at least in its main aspects. It is almost certain that the behaviour of electrons, both positive and negative, and photons (i.e. electromagnetic radiation of high energy), is almost completely described by the existing quantum theory. This theory predicts that an electron in traversing matter has a large chance of emitting a photon of considerable energy, and such a photon has a similar large chance of being absorbed by the production of a pair of positive and negative electrons. The mean range of an energetic electron before emitting a photon of large energy, and the mean range of a photon before producing a pair, are about the same, and amount only to about 0·4 cm. of lead. Thus energetic electrons and photons are not at all penetrating, but on the contrary are rather rapidly absorbed. Since a single incident electron rapidly produces photons and these photons produce positive and negative electron pairs, and each electron of a pair rapidly produces more photons, and so on, the absorption of an energetic electron produces what is called a "cascade shower" of positive and negative electrons. These showers form one of the most characteristic features of cosmic-ray phenomena. A photograph of one is given in Fig. 4 (see Plate). The majority of such showers are relatively small, containing a dozen or so rays, but a few are very large and may contain up to 20 000 rays or more. The amount of ionization produced by a large shower is such that it is quite easily detectable with a sensitive electroscope.

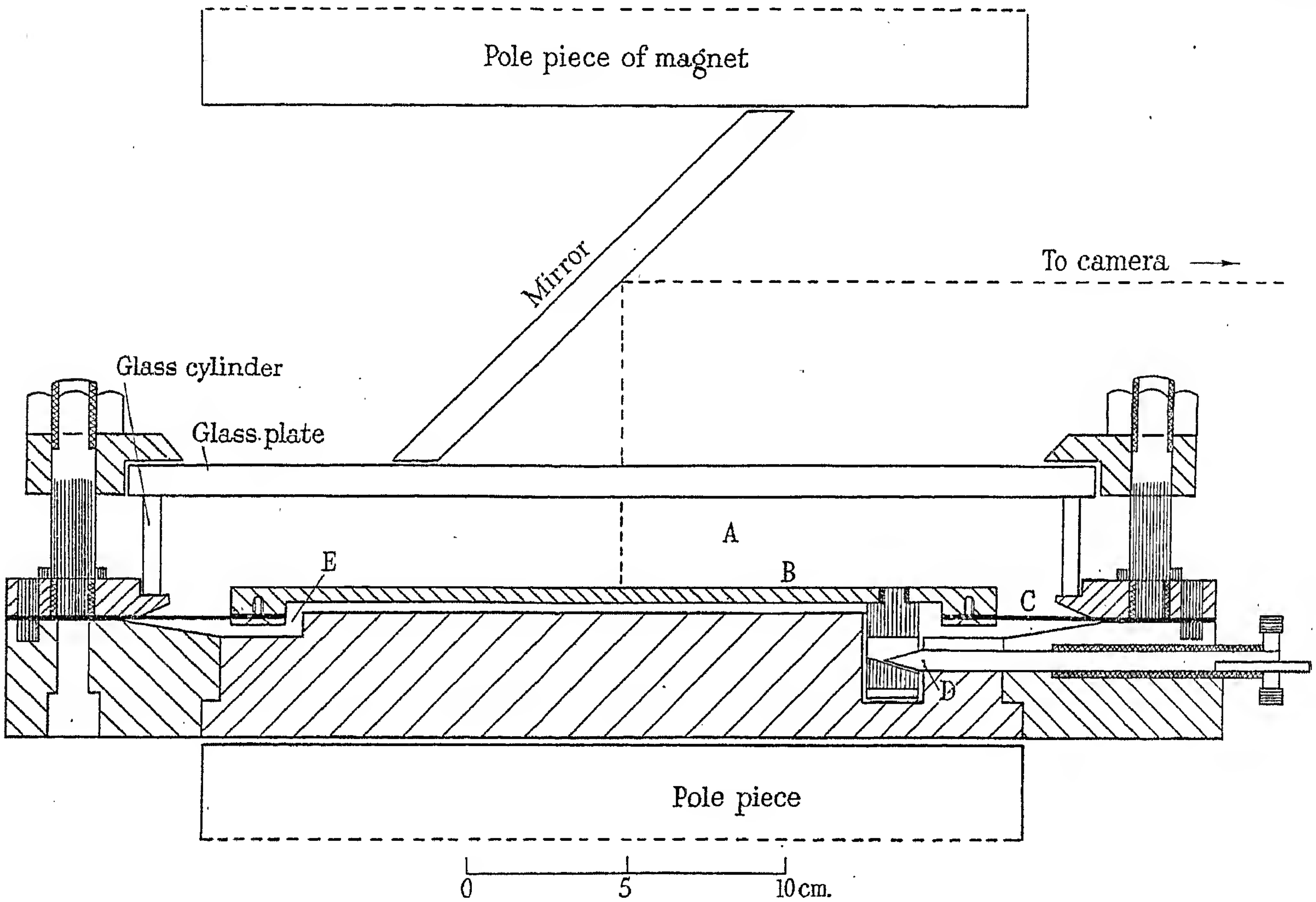


Fig. 1.—Diagram of cloud chamber for use between poles of electromagnet.

Recently, through the work of Auger and his collaborators, showers have been found which are very extensive, i.e. they extend over an area of, say, 10 000 m^2, with a mean density of at least a few, and possibly of many, rays per square metre. These showers are thought of as due to a cascade shower started by a single very energetic electron incident on the earth's atmosphere. Such a shower will then produce a gradually widening column of rays extending from the top of the atmosphere to sea level, and containing, at its maximum, some 20 000 to 100 000 rays. The energy of the incident electron required to produce such a shower may be as high as 10^{15} electron volts or more.

The mass of the mesotron may be deduced from photographs obtained with the type of cloud chamber shown in Fig. 1, from which it is possible to determine the ionization along the track and the curvature of the track in a magnetic field. Unfortunately, tracks of mesotrons which are slow enough to be of use for this purpose are very rare; and so far the total number obtained by experimenters all over the world which are both slow enough and technically good enough to be of any use at all for an accurate mass determination are very few indeed. A closely related method is to measure not the ionization but the change of curvature $\Delta(H\rho)$ of a slow ray in a magnetic field H, while passing through a metal plate. Since tracks suitable for this purpose are more frequent of occurrence than those slow enough to permit the ionization method to be used, and since the change of curvature is probably rather easier to measure accurately than the ionization, this method may prove a better one for accurate determinations. A critical survey of the best existing data suggests that the mass of the mesotron is about 170 times that of the electron, with a probable error of about 10 %.

The possibility that the mesotron might be unstable was first suggested by the Japanese theoretical physicist Yukawa, as a result of a theory of nuclear binding energies. It has become usual to try to explain the forces between the constituent neutrons and protons, out of which nuclei are built, as being due to the "exchange" of some other subsidiary particle between them. At first this subsidiary particle, whose action may be likened to the function of providing the "glue" by which nuclei are held together, was thought of as consisting of electrons. Now this model of a nucleus had to explain the additional feature that some nuclei are unstable and break up spontaneously with the emission of an electron—that is, some nuclei are radioactive bodies emitting β-rays. Thus to explain β-decay, the electron, while jumping continually from one nuclear particle to another, had to be given a small chance of escape. However, it proved impossible to reconcile the observed chance of escape, as deduced from the periods of β-decay bodies, with the known forces between the nuclei. The theory would not give both the right forces and the right decay. This remained a most serious difficulty for nuclear theory, until a suggestion of Yukawa showed a way if not of resolving the difficulty, at least of avoiding it. Yukawa showed the advantage of supposing that the virtual particles, which give rise to the exchange force between nuclear particles, are not electrons but a new hypothetical particle of mass about 100 times that of an electron. The advantage of the introduction of the new heavy particle of mass μ lay partly in the fact that such a particle has a characteristic wavelength $\lambda = h/(\mu c)$ of the order of 3×10^{-13} cm., which is the order of magnitude of the size of nuclei. Here h is Planck's constant and c is the velocity of light. Thus the heavy particle had, so to speak, the right size to form a suitable "glue" for the constituent protons and neutrons in nuclei. This conception of the interaction of two particles (e.g. a neutron and a proton) by reason of a continual "exchange" of a third particle (e.g. a mesotron) between them, may appear to be rather a strange one. Exchange forces were first introduced into physics in connection with the wave mechanical theory of the homopolar chemical binding. For instance, a positive hydrogen ion consists of two protons which can be regarded as bound together at a distance of the order of 5×10^{-9} cm. by the single electron which makes a continual exchange between orbits round the two protons.

This "exchange" effect has been aptly referred to as a "playing ball" effect, and from this point of view, perhaps, it does not appear so strange. For suppose one is observing from a considerable distance a grassy field, and one sees two white-clad figures moving about relative to each other, but always keeping within a limited distance of each other, then one can safely make the assumption that the agency or "force" which is keeping them together is a tennis ball. In a rather analogous way does the mesotron bind together the constituent particles of a nucleus!

But something further had to be added to the theory in order to explain the β-decay of radio-active nuclei. It was now not sufficient to suppose that the heavy particle sometimes escaped from the nuclei, as the electron was supposed to do in the older theory, because no radio-active body had ever been observed to emit mesotrons. But since electrons are emitted, it had to be supposed that the mesotrons binding a nucleus together had themselves a chance of disintegrating into electrons. It then followed that if such mesotrons existed as free particles, instead of only as bound particles in the nucleus, they must be unstable and decay spontaneously into electrons. From β-decay data, the mean life could be estimated to be about 10^{-6} sec.

As soon as the penetrating cosmic rays were identified as being much heavier than electrons, it became natural to identify them with Yukawa's postulated particles, and therefore to suppose that they were unstable. This suggestion that the penetrating cosmic rays of mass about 170 times that of an electron are unstable, with a mean life when at rest of only about a millionth of a second, has proved a most fertile hypothesis and has provided an explanation of some most curious phenomena which had hitherto defied explanation.

These phenomena related to the observations that penetrating cosmic rays were more absorbed in gaseous absorbers than in the same mass of a dense material such as water, and again more absorbed in air at a lower pressure compared with air at a higher pressure. These phenomena received a natural explanation on the hypothesis of the instability of the mesotron, since the greater absorption of the rays in material at a low density simply follows from the greater geometrical distance the rays travel before being absorbed and so the greater time there is for them to decay spontaneously. When they do decay they turn into electrons, which are rapidly absorbed. Measurements, therefore, of the change of absorption of mesotrons with decrease in the density of the absorber are really measurements of the decay period of the mesotrons.

A most interesting application of relativity theory must be taken into account in studying the effects of the decay of the mesotrons. Relativity theory, as expressed, for instance, in the form of Lorentz's transformation of co-ordinates, shows that a clock which is

moving very fast, i.e. with a velocity nearly that of light, will go very slow, compared with when at rest. If the periodic time of the clock mechanism is T_0 when at rest, then when the clock is moving with velocity v its periodic time will be $T = \gamma T_0$

where $$\gamma = \frac{1}{\sqrt{[1-(v^2/c^2)]}}$$

When $\gamma >> 1$, the energy of a particle is given by

$$W = \gamma \mu c^2$$

where μc^2 is its rest energy. Exactly the same relation must exist between the mean time of decay of a moving mesotron and its velocity; in fact, a mesotron acts like an atomic time bomb with a mean life which is roughly proportional to its energy. In the atomic world at least, the faster one goes the longer one appears to others to live.

Now the average energy of the cosmic-ray mesotron at sea level is about 3×10^9 electron volts, and since μc^2 for a mesotron is about 8×10^7 electron volts, we have $\gamma \simeq 40$. Hence the average mesotron at sea level lives about 40 times longer than it would if at rest.

Analysis of the difference between the observed absorption of mesotrons by air and by water shows the decay time of a mesotron at rest to be $T_0 = 2{\cdot}5 \times 10^6$ sec. An average mesotron at sea level will therefore have a mean life of about $40 \times 2{\cdot}5 \times 10^{-6} (=10^{-4})$ sec., and so will travel on the average a distance of $l = cT \simeq 30$ km. before decaying. Thus the intensity of a beam of mesotrons of 3×10^9 electron volts would decrease exponentially, even in free space where there is no matter, with a mean range of this value.

We will now apply this result to the calculation of the effect of the change of temperature of the atmosphere on the intensity of cosmic rays. We assume that the mesotrons are formed in the upper levels of the atmosphere at a height of, say, 15 km., and then travel vertically downwards towards the earth. Since the mean range before decay is about 30 km., a considerable fraction, of the order of one-quarter, will decay before reaching sea-level. In summer, when the temperature of the atmosphere is high, the atmosphere is expanded and reaches to a greater height. Then the mesotrons will be formed higher up, and so will have farther to travel and more chance to decay. Hence the intensity of the rays at sea-level will be less in summer than in winter.

If δz is the mean increase of height of the layer where the mesotrons are found in summer compared with winter, and if $\delta\theta$ is the corresponding mean difference of the air temperature, and if as before l is the mean range before decay of the mesotron, then the temperature coefficient of the rays is

$$\alpha = -\frac{1}{l} \cdot \frac{\delta z}{\delta \theta}$$

Taking $l = 30$ km. and $\delta z/\delta\theta = 40$ m. per deg. C., we have $\alpha = 0{\cdot}13\,\%$ per deg. C. The observed values are just of this order, but vary considerably from place to place owing to the effect of local meteorological conditions. This observed decrease of the intensity of cosmic rays with increasing temperatures had been one of the most difficult phenomena to explain till the instability of the mesotron was recognized. Now it seems that it is explained very simply and roughly quantitatively by the effect of this instability.

Bohr has pointed out how the decay of mesotrons of high energy in the atmosphere provides a very illuminating example of fundamental relativity considerations. Consider a mesotron traversing a vertical distance d in the atmosphere. To an observer at rest relative to the earth, the mesotron appears to have a very high energy $W = \gamma\mu c^2$, where $\gamma \simeq$ (say 40), and so its mean life is $T = \gamma T_0$.

The chance that it decays in traversing the distance d is then, roughly, provided $d << l$,

$$p = \frac{d}{l} = \frac{d}{c\gamma T_0}$$

But it is perfectly permissible, at least for a theoretical physicist, to imagine himself moving with the mesotron, and so observing it from a system of co-ordinates in which the mesotron is at rest. Now, relative to such a co-ordinate system, the mean life of the mesotron is T_0 and not γT_0, and so it would appear that the probability of decay in traversing the atmosphere is not $d/(c\gamma T_0)$ but $d/(cT_0)$, which is much larger. But the chance of the mesotron decaying cannot possibly depend on the co-ordinate system from which we choose to observe it. Where is the error of our reasoning? We have forgotten the Fitzgerald contraction of the height of the atmosphere, which is of course moving very fast relative to the mesotron. In this co-ordinate system the atmosphere has not a thickness of d, but is contracted to a thickness of only d/γ. Thus the expression $p = d/(c\gamma T_0)$ for a co-ordinate system at rest relative to the earth becomes

$$p = \frac{d/\gamma}{cT_0}$$

for a co-ordinate system at rest relative to the mesotron. This presentation brings out very clearly the essential relation between the Lorentz transformations of time and space.

It must certainly be considered a most lucky fact that nature has presented for our study in the form of mesotrons of high energy almost the ideal clock in very rapid motion to give substance to the theories of relativity.

Although many obscure facts have been clarified by the discovery of the mesotron and the recognition that it is unstable, there are still a great number of points on which our knowledge is most incomplete. It is not known how the mesotrons are produced in the upper atmosphere, nor what are the incident stable rays which produce them. Again, it is not known what happens when a mesotron comes to rest at the end of its range. Theory leads us to expect that it should decay into an electron of energy $\frac{1}{2} \times 80 (= 40)$ million electron volts, the other 40 million electron volts going to the energy of the unobservable neutrino. But what evidence there is at present, and it is very slender, does not support the existence of this process.

The subject of cosmic rays has been full of surprises and unexpected discoveries. It is most probable that still more are in store for us.

THE CORROSION OF UNDERGROUND CABLES

By W. G. RADLEY, Ph.D.(Eng.), Member, and C. E. RICHARDS.*

Paper first received 6*th May*, 1938, *and in revised form* 7*th January*, 1939; *read before a Joint Meeting of the* TRANSMISSION SECTION OF THE INSTITUTION *and the* CHEMICAL ENGINEERING GROUP OF THE SOCIETY OF CHEMICAL INDUSTRY, 8*th March*, 1939.)

SUMMARY

Modern telephone systems utilize extensive networks of bare lead-sheathed cables drawn into earthenware conduit. As with other underground structures, the cable sheaths are liable to corrosion. In the absence of electrolytic stimulation the rate at which this takes place depends more on the nature of the soil waters, etc., than on the composition of the sheathing material. The danger is increased by the electrolytic action of stray currents passing between the sheath and its environment by ionic paths. Such currents may be the result of leakage from electric traction systems with uninsulated return, or may arise from the setting-up of primary-cell actions due to inhomogeneities in the environment of the cable.

Laboratory examination of samples of corroded sheathing, together with chemical analysis of the corrosion products and soil waters, enable definite conclusions to be reached as to whether there has been electrolytic stimulation. In general, this produces a pitted surface, an intercrystalline type of attack and, with normal soil waters, a corrosion product rich in chloride. The actual field measurement of the intensity of the current discharge from the sheath in the dangerous anodic areas does not yet appear possible. Useful information has, however, been obtained from apparatus recording the sheath current at two points a short distance apart. Increasing use is also being made of standard "half-cell" electrodes for the accurate determination of the small potential differences existing between a sheath and its immediate surroundings.

Electrical drainage has been used extensively abroad for the protection of cable sheaths in the stray-current fields of electric tramways. In Italy this method has been used with shunted insulating gaps in the cable sheaths in such a way that there is no increased danger to other buried pipe systems. The British Post Office has been successful in obtaining protection solely by the planned insertion of numerous insulating gaps in a cable system. Protective coverings are in use, although they make the pulling of cables into and out of cable ducts more difficult. It has been found, however, that the chemical attack of corrosive soil waters may be retarded by the addition of a chemical inhibitor to the lubricant used when the cable is first drawn in.

CONTENTS

* Post Office Engineering Research Station.

CONTENTS—*continued*.

CONTENTS—*continued.*

(1) INTRODUCTION

A large part of the capital of every telephone administration is buried underground in the form of cables, which in Great Britain alone contain 12 200 000 miles of wire. Much invested money is also represented by the lead-sheathed underground cables belonging to electric lighting and power undertakings. Taken together, the sheathing of these two types of cable is one of the largest single uses of metallic lead in any country.

Lead is one of the least corrodible of metals. Many lead roofs exist which are 5 centuries old. The Romans employed lead water pipes, and some of these are said to be in use to-day. In part, the inertness of the metal when exposed to the air is due to the formation of a protective film on the surface. But when a lead-sheathed cable is buried in the earth or drawn into a conduit the soil particles and ground waters with which it is brought into contact may be such that chemical action, resulting eventually in perforation of the lead sheath, takes place. Removal of the metal from the surface of the sheath is accelerated by the presence of stray electric currents circulating in paths which pass from sheath to earth by non-metallic contact.

Comparatively little has been published in this country concerning the corrosion of underground cables, although in 1922 Mr. S. C. Bartholomew* gave Post Office engineers an excellent review of the subject having regard to its importance to a growing underground telephone-cable network. Since then, a paper has been published in the *Journal*† describing the method adopted in Australia for mitigating the effects of tramway stray currents. The object of the present paper is to review the work that has been done during the past few years, to describe new methods of field measurement that have been successfully used, to give an idea of the role of the chemist in the diagnosis of some of the more obscure cases of failure, and to indicate the protective measures which are available.

The importance of the problem to the telephone engineer cannot be too strongly emphasized. Ingress of a very small amount of water resulting from a single perforation of a telephone cable sheath may completely destroy dry paper insulation and throw several hundred circuits out of service. Although with other services a single perforation of cable sheath or pipe wall may not have such immediate results, corrosion is a matter of great economic importance to all utility concerns employing underground distribution.

* See Bibliography, (1). † *Ibid.*, (10).

(2) THE UNDERGROUND CORROSION PROBLEM IN VARIOUS COUNTRIES

(2.1) Great Britain

The replacement of corroded telephone cables cost the Post Office £48 000 in the year 1935–36. The cost of corrosion has been growing somewhat during past years. This is more than accounted for by the rapid increase in the total mileage of underground cables and in the average age of a very large cable network. It is hoped that the annual cost of replacements may be held in check, if not reduced, by the aid of certain mitigative measures which will be described later.

It is not possible to give a figure for the average reduction of life of the cable system as a whole due to corrosion, as the life of some cables may be ended within a few years as a result of a single perforation while the life of others may be unaffected by corrosive attack.

Localities exist, chiefly in certain provincial cities, where corrosion due to tramway stray currents is very rapid. There are also exchange areas in rural districts, chiefly in South-East England, where the soil water is so rapidly corrosive to lead that it is now the normal practice to install there cables with some form of protective covering.

(2.2) Other European Countries

The experience of European administrations differs considerably. In Germany, where regulations (see Table 6) are rigorous, electrolysis gives less trouble than in many other countries. Much study has been made of the problem in France, but expensive mitigative measures have not been adopted except in rare cases. On the other hand, in some Italian cities underground cables are seriously endangered by the stray currents from existing tramway systems and very elaborate and expensive schemes of protection, to be described later, have been evolved. The problem in Italy includes many long-distance telephone cables laid adjacent to, or within, the right of way belonging to railways electrified with direct current. In Switzerland the damage suffered by gas and water services gave rise to discussion between all interested parties prior to 1914. As a result of these discussions and with the collaboration of the Swiss Association of Electricians a committee was formed to study protective methods. This was replaced later by a permanent Commission supported by gas, water, telecommunication, and traction services, which is responsible for all testing work and for the planning of all mitigative measures.

(2.3) North America

In many cities in the U.S.A. the corrosion caused by stray currents from street railways presented a serious problem, and protection was sought by electrical-drainage connections (see Section 7.6) between the endangered cables and the tracks of the street railway.

Many of these street railway systems have now been abandoned, and a principal problem confronting the Bell Telephone Companies is that of corrosion arising from the circulation of self-generated currents. Roughly 60 per cent of the total telephone cable mileage in the U.S.A. is suspended from messenger wires between poles, and is thus immune from corrosion trouble. The underground corrosion problem has, however, probably received more study in the U.S.A. than elsewhere, owing to its importance to a country in which, in addition to the usual gas, water, telecommunication, etc., services, there are 125 000 miles of buried pipes for the transport of petroleum and its products.

(2.4) Australia

In the larger cities in Australia, serious electrolytic corrosion has resulted from the operation of street-car systems built up to conform to the old British Board of Trade Regulations.* The corrosion rate, however, appears to have been much more rapid than in towns of corresponding size in Great Britain, and has stimulated the formation of local committees to consider mitigative measures. Such committees now function in the three principal cities in Australia.

(2.5) Japan

A good deal of work has been published, but the worst trouble appears to arise from very close proximities between cables and electrified railways.

(3) METHODS OF UNDERGROUND CONSTRUCTION

(3.1) Duct Lines

The first essential of any underground cable system distributing telephone service is flexibility. That is to say, it should be possible to install additional cables along a given route or to replace an existing cable by one of greater capacity or more modern design at the minimum cost. In the centres of population such considerations lead to the use by almost every telephone administration of some form of conduit system into which bare lead-sheathed cables may be easily drawn.

The standard form of conduit used by the Post Office consists of good-grade, glazed-earthenware, self-aligning ducts. These have from 1 to 9 cable-ways, and spigot and socket joints which are made fast with a hot jointing compound composed of french chalk, coal tar, and pitch. The Bell System companies in the U.S.A. use a duct made of similar material. The ends of adjoining ducts are, however, brought together with a simple butt joint around which is wrapped a plaster bandage of cement and muslin gauze. In practice, it is impracticable with either of these forms of construction to prevent the infiltration of soil waters through small fissures which may sometimes develop at duct joints. Surface water accumulating in the manholes and jointing chambers may flood the cable ducts. Quite apart from these causes, conditions frequently result in the condensation of drops of moisture on the sheathing and in the cable ducts. When more than 18 ways are required, or where congestion of other mains would render self-aligning ducts uneconomical, British practice may use ducts of octagonal external section. The ducts are made of well-burnt clay and are glazed on the inside only. They are enclosed in a solid block of concrete. The construction is more expensive than that of the usual form of duct line. Quite extensive use is made of concrete ducts in France and Germany. Concrete conduit has been extensively employed for power cables in the U.S.A. The use of asbestos-cement pipes with a rubber ring joint is being tried experimentally by the Post Office.

* Now the Ministry of Transport Regulations.

(3.2) Monolithic Constructions

Two types of construction which have attracted attention in Europe are of interest. The first is that tried in France, of monolithic concrete conduits constructed on site. After a concrete bed has been laid, a number of water-inflated rubber hoses are put into position to correspond with the "ways." Concrete is built up around and over these and, after it has set, the hoses are deflated and withdrawn by pulling the distant end through from the inside. An entirely novel form of construction is now being used in Italy in which a concrete trough is built with the aid of shuttering, and non-corroding steel frames carrying porcelain rollers are inserted at intervals. The latter support the cables clear of any water, etc., which is drained from the bottom of the trough. The top of the trough is closed by a precast concrete slab. Labour costs would probably prohibit the use of this method in most countries.

(3.3) Iron and Steel Pipes

Cast-iron pipes were used for many early Post Office cables. They are not nowadays a usual form of construction, although steel pipes are standard where the depth of the cable below the road surface is abnormally shallow—where bridges have to be crossed, etc. Steel and iron pipes also find a limited application abroad.

(3.4) Wooden Troughing

Impregnated wooden troughing is very little used in this country, but is widely used in the U.S.A., particularly for subsidiary cables. It has also been employed extensively for main cables on the Pacific coast, where it possesses an economic advantage.

(3.5) Armoured Cables Laid Directly in the Ground

On the continent of Europe the use of cables laid directly in the ground is common outside cities. Such cables are served with a wrapping, usually of hessian impregnated with a bitumen compound and jute, and protected mechanically by an armouring of steel wires or tapes. Apart from a few recent cables, this method of construction has been very little used in Great Britain.

(4) THE THEORY OF UNDERGROUND CORROSION

In any discussion of corrosion there are a few terms which are bound to be used, but which are sometimes given slightly different shades of meaning by different writers. In order to avoid confusion, the meanings associated by the present authors with some of these terms are stated below.

(4.1) Corrosion

By corrosion is meant the destruction of a metal (by conversion into some compound) by chemical or electrochemical action. The term as applied to cables includes chemical attack due to the action of corrosive soil waters, and electrolysis due to electric currents circulating from any cause whatsoever. It does not, however, include that embrittlement of the metal which is caused by alternating mechanical stresses.

(4.11) Chemical corrosion.

This is the destruction of the metal by the action of a corrosive material—such as soil water, sewage, or moist lime—on the metal, this action remaining unstimulated by any external electrical force. Chemical corrosion is generally accompanied by circulating electric currents in the corroding metal, usually having only a very restricted path. In certain circumstances, however, these currents may flow for long distances, and the corrosion then taking place at the points where the current leaves the metal is termed natural current electrolysis. This discrimination is necessary, since the resulting attacks on the metal differ, as also do the methods of prevention.

The difference between the two can conveniently be illustrated by the behaviour of zinc and copper. In Fig. 1 are shown diagrammatically two zinc-copper systems corroding in a salt solution. In (*a*), (*b*), and (*c*) we have a system which would be regarded as chemical corrosion, arising from impurities in the zinc. The action would be local, the anodic and cathodic areas being quite close, and the products of the action would diffuse into one another, as shown in the enlarged view in (*d*). There is, in the ordinary way, no chance of measuring the currents flowing as shown in (*a*), (*b*), and (*c*). In (*e*) we have a condition which would give rise to natural current electrolysis. The two electrodes are separated sufficiently to be treated as separate bodies: it is easy to measure the current flowing from one part to another, and if the separation is large enough there is little or no chance of the corrosion products interdiffusing. There is, of course, no need to assume the presence of a different metal to explain corrosion at a point. So long as any of the surface conditions are not uniform, the system is potentially one which will corrode. One of the most notable causes of corrosion is difference in the oxygen concentration from point to point in the electrolyte.

(4.12) Electrolysis.

This is that variety of corrosion which is due to the flow of current by an ionic path to or from a cable sheath. It may be subdivided, as shown below, into three main divisions.

Natural current electrolysis is corrosion which is set up by circulating currents developed in the cable system itself. The origin of these currents may be differences in the sheathing material, but is more likely to be differences in the earth through which a cable passes, as shown in (*f*), Fig. 1. The currents giving rise to natural current electrolysis are generally quite steady and may be very small. They are sometimes called "long-line currents."

Stray-current electrolysis is that in which current flowing to or from the cable sheath is derived from some external system. A frequent cause of such current is leakage from d.c. tramways or electric railways with uninsulated return rails.

Alternating-current electrolysis is that in which the currents circulating in the corroding system are derived from a.c. circuits either by leakage or by induction.

(4.2) Applicability of Faraday's Laws

In dealing with electrolysis cases, a point which has frequently arisen is whether Faraday's laws of electro-

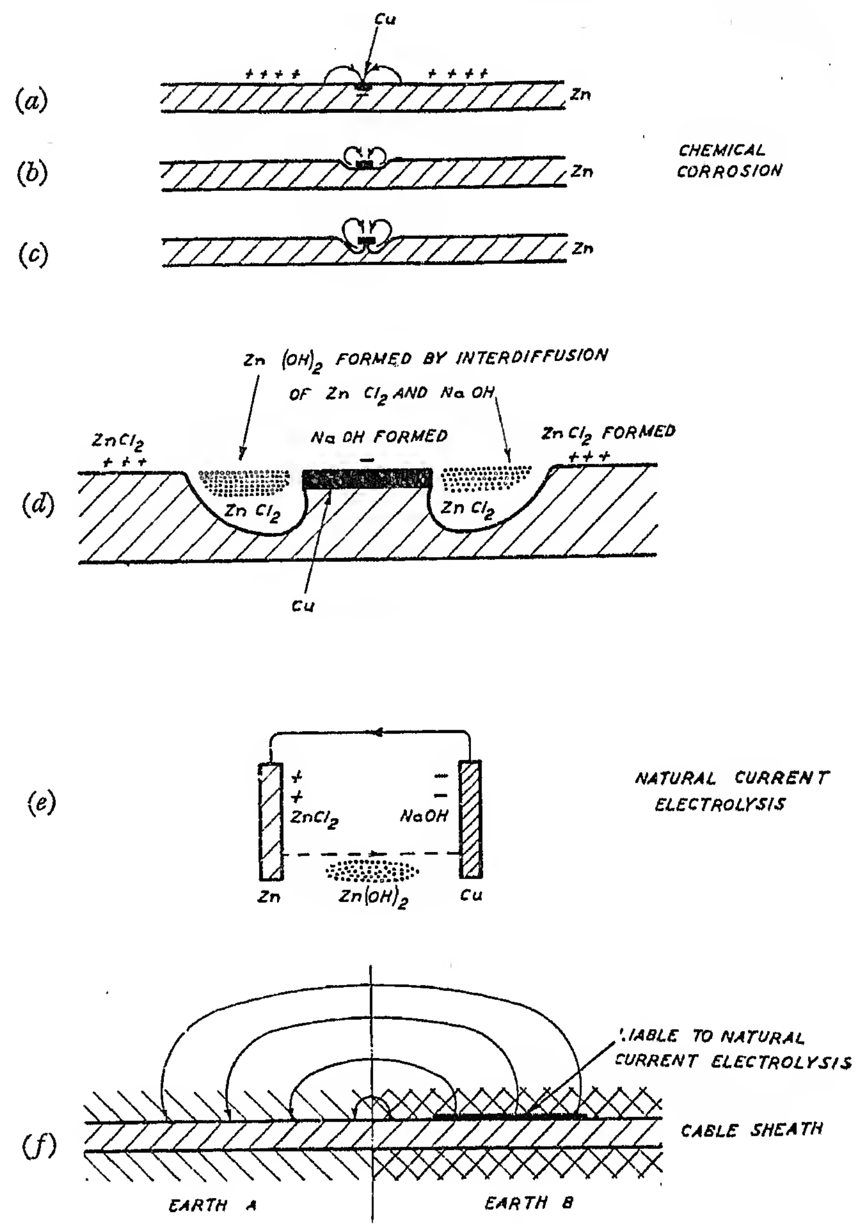


Fig. 1.—Generation of circulating currents.

lysis are strictly obeyed. It is often pointed out that the corrosion is much greater than would be expected from the magnitude of the currents leaving the surface of the metal. This may be true, if no allowance is made for those restricted-path circulating currents which cause "chemical corrosion" and which are generally overlooked. If due allowance is made for the chemical corrosion which can take place at the same time as electrolysis, the laws can be shown to apply, as is shown in Table 1—compiled from tests in natural earth water.

(4.21) The amphoteric nature of lead.

Lead is one of those elements whose oxides can act either as acids or as bases. In the ordinary way lead

Plate **1**

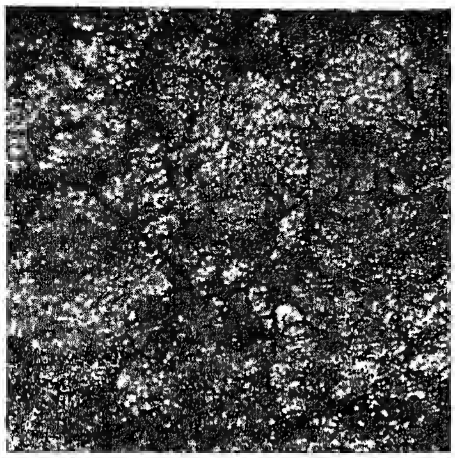


Fig. 2.—Typical intercrystalline attack caused by electrolysis at 0·25 volt. (Magnification, 25.)

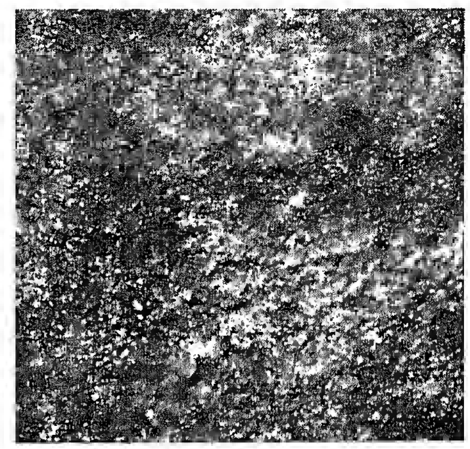


Fig. 3.—Chemical corrosion occurring in same water as Fig. 2, without electrolytic stimulation. (Magnification, 25.)

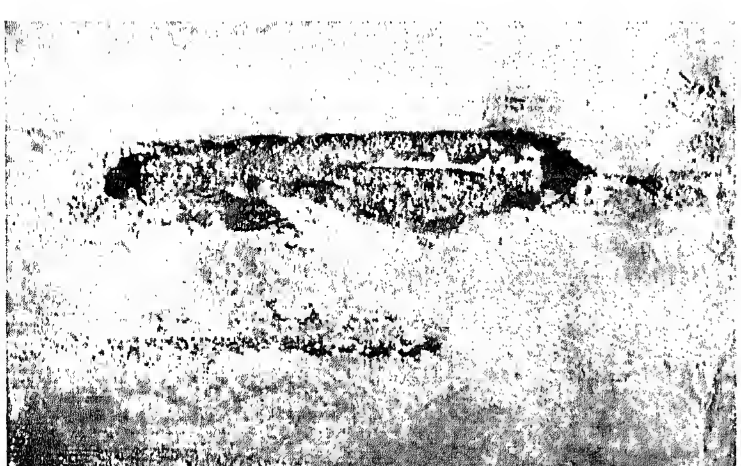


Fig. 4.—Lead cable-sheath pitted as the result of electrolytic corrosion.

Fig. 5.—Lead cable-sheath perforated by "burn-out."

Plate 2

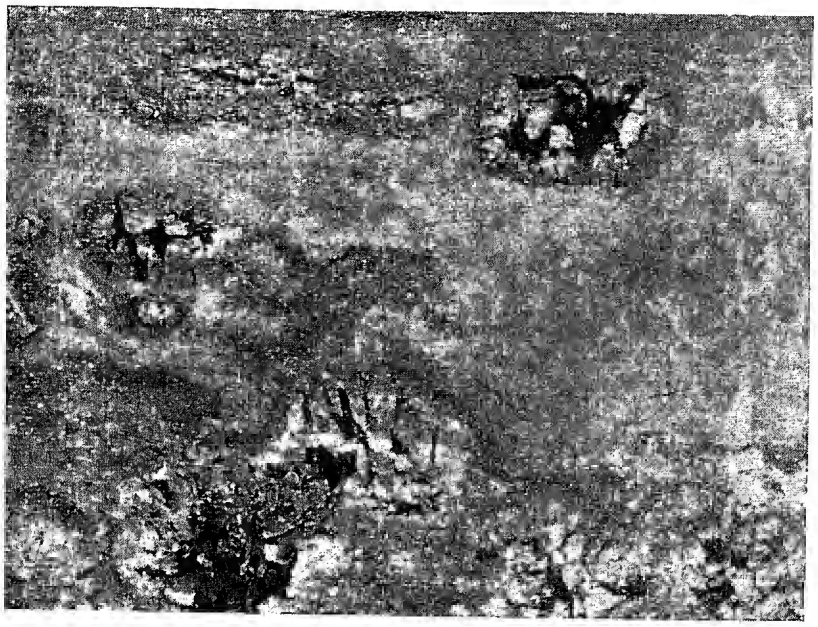


Fig. 6.—Corrosion produced by fresh Portland cement.

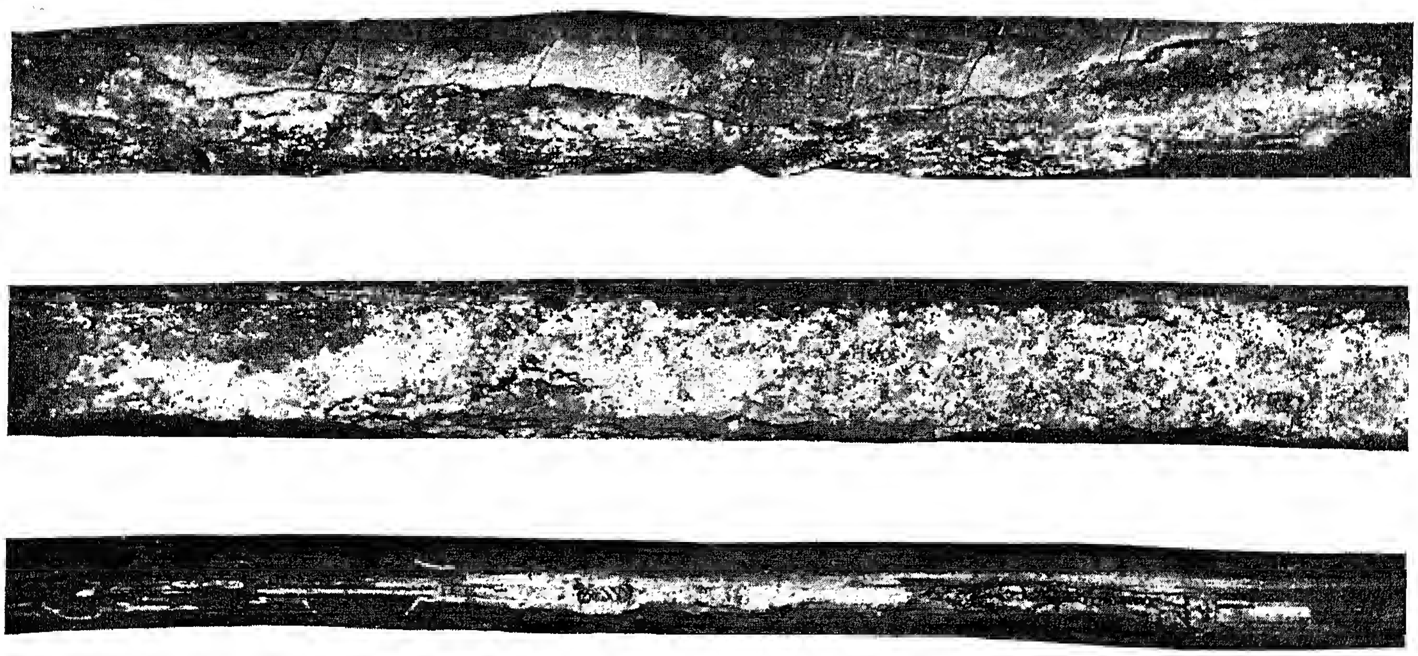


Fig. 7.—Corrosion resulting from condensation in iron pipe.

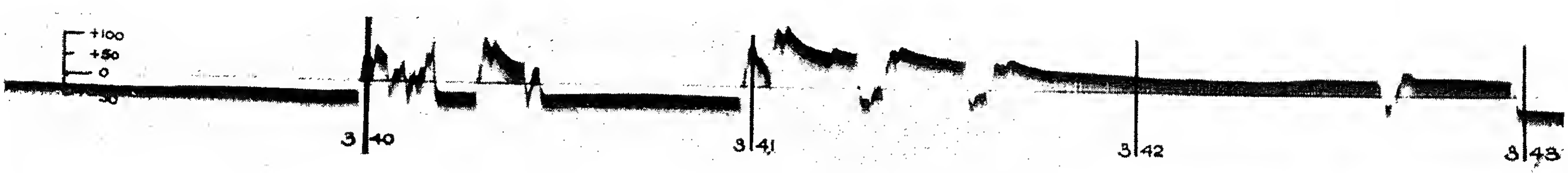


Fig. 12.—Record obtained by the use of a loop galvanometer and photographic recorder, showing current in telephone cable sheath resulting from movements of a single tramcar.

will corrode—as will most other metals—if made anodic in an electrolyte, giving as corrosion product salts such as lead chloride $PbCl_2$. On the other hand, in certain environments it may corrode if made cathodic to the electrolyte, giving in this case a corrosion product such as sodium plumbite. This factor should not be disregarded when protection by means of electrical drainage or cathodic polarization (Sections 7.6 and 7.7) is under consideration. Fortunately, however, cathodic corrosion is rare.

Table 1

APPLICABILITY OF FARADAY'S LAWS

Coulombs passed	Theoretical loss	Actual loss	Electrolytic loss
	mg.	mg.	mg.
0	0	47	0
14·5	56	105	58
15·9	61	123	76
24·5	94	139	92

(4.22) Magnitude of corrosion with alternating and with reversing currents.

This depends to some extent on the frequency of reversal, and when this is rapid, e.g. 50 cycles per sec. alternating current, the amount of damage has been popularly assessed as 1 % of that which would be caused by the action of a similar quantity of direct current. Laboratory experiments have been carried out by the authors to determine the effect of more occasional reversals of potential between cables and "earth" or cables and tramway rails. They have shown that, unless there is a large excess current flow in the direction in which the lead is cathodic, current flow in the other direction always results in corrosion of the lead. The amount of corrosion is somewhat greater than that equivalent to the net current flow, but approaches it when the amount of current flow with the lead anodic much exceeds that with the lead cathodic to its surroundings. For cases in which the amounts of current flow in the two directions differ only slightly, it is impossible to give a factor relating the actual corrosion with the net current flow. Table 2 gives some typical experimental results using direct current reversed or interrupted by a commutator. The time of a complete cycle varied from 1 to 12 sec.

Table 2

CORROSION OF LEAD PLATES BY INTERMITTENT AND REVERSING CURRENTS

Ratio of cycle		Duration of cycle	Corrosion equivalent of coulombs passed (mg. of lead)		Corrosion actually measured (mg. of lead)
Time, positive	Time, negative		Gross	Net	
		sec.			
All positive	—	—	826	826	888
10	1*	12	1 033	977	985
3*	2	1	793	353	367
3*	2	12	485	234	242
3	2*	1	316	53	73
2*	3	12	390	- 89	— 40

* The current in this direction was greater than that in the reverse direction.

(4.3) Concentration Cells

It is well known that the potential of a metal to a given salt solution is partly governed by the concentration of the electrolyte, and that primary cells of the type $Pb : KCl_{(1)} : : KCl_{(2)} : Pb$ will give a definite e.m.f. which depends on the relative concentrations of the two KCl solutions. If the two lead plates in such a cell are connected by a wire, current will flow through the wire, and one of the plates will corrode. Similarly, we may have a cell such as $Pb : KCl : : KNO_3 : Pb$, which will also produce current and corrosion. Many cases of natural current electrolysis arise from this cause, the cell being of the type Pb : $earth_{(1)}$: : $earth_{(2)}$: Pb. Small currents only are produced, but, as already stated, they are steady and flow for a long time.

(4.4) The Stray-current Circuit

A classic paper in connection with stray-current electrolysis began with the following sentences: "The leakage of electric current from street railway tracks used as return conductors is the principal cause of electrolytic corrosion of underground metal structures. Occasionally, electrolysis is due to other causes, such as the leakage of current from power or lighting circuits, but such corrosion is infrequent and usually confined to small areas." Theoretical calculation of the traction current flowing in buried pipes and cables demands definition and evaluation of the resistance of the various conductors to the surrounding semi-conducting earth and of the mutual resistances between them. Study of these resistances was undertaken by the C.M.I.* in 1932. It appears† that, knowing the distribution of voltage along the track, calculation of the current entering the ground is an easily approachable problem in the absence of other metallic systems. The adoption of simplifying hypotheses leads to a solution which is relatively simple and sufficiently approximate. On the other hand, this problem is greatly complicated by the presence of buried pipes or cables.

Calculation of the current entering or leaving a pipe or cable is an even more difficult matter, as the simplifying hypotheses, permissible in the first case, can no longer be applied. Differing pictures of the distribution of leakage current in the earth and the part carried by buried pipes and cables result from wide generalizations which make theoretical solution possible. In practice,

* *Commission Mixte Internationale pour les expériences relatives à la protection des lignes de télécommunication et des canalisations souterraines.*
† See Bibliography, (14).

there are additional factors which enter to spoil any generalization. These are irregular loading of the track, high-resistance rail joints, heterogeneity of the soil, variation in the separation between the track and the endangered system and in the insulation resistance of both, the presence of other buried pipes and cables, etc. Because of such factors the very complicated cases met with in practice are not usually capable of solution.

(4.5) " Burn-outs "

The breakdown of an electric supply main has often been followed by the failure of a nearby telephone cable. Such failures, termed " burn-outs," are mentioned later, in Section (5.31).

(5) CHEMICAL ASPECTS

Chemical knowledge can be applied in many ways in dealing with the corrosion problem, and one of the most important of these is in the determination of the cause of faults which have occurred. One advantage of doing this type of work chemically is that it can be conducted principally in the laboratory, using specimens of the damaged cable, and samples of earth and water taken from the vicinity of the fault.

A set of samples in connection with a cable-corrosion case may consist of part of the damaged sheath, water collected from the duct line, mud scraped from the duct, fabric which has been in contact with the sheath, yarn used for packing pipe joints, soil from the neighbourhood, etc., together with any items which the local officers consider to be relevant or interesting.

The most important examination to be made is that of the cable sheath. This is generally dirty when received, and is first of all cleaned and freed from grease by rinsing with benzene. In the case of the smaller specimens, more effective cleaning is usually achieved by the use of a carbon-tetrachloride or trichlorethylene-vapour degreaser. When it has been degreased, the specimen is ready for a microscopic and chemical examination.

(5.1) Appearance of Corroded Cable-sheathing

(5.11) Microscopic examination.

The specimen is examined under a low-power microscope, a Greenough binocular pattern being very convenient for the purpose. Particular attention is paid to the general appearance and texture of the corrosion product. This may be: (*a*) Brown powdery masses. (*b*) A white opaque substance which tends to flake rather than crumble when crushed with a needle point. (*c*) Translucent watery crystals, some of which may possess a recognizable shape—tetragonal tablets—but most of which will be present as masses of translucent material, looking, when magnified, rather like washing soda, and behaving like it when prodded with a needle. (*d*) Bright red pockets or masses of corrosion product. (*e*) Corrosion product in the form of white needles. (*f*) Corrosion product in the form of yellow flakes.

The significance of these microscopic observations will be discussed later.

(5.12) Distribution of corrosion.

(*a*) Generally spread over the surface.

(*b*) Confined to pits or furrows on the lower part of the sheath.

(*c*) Confined mainly to the upper part of the sheath.

(5.13) Type of corrosion of the metal.

In order that the type of the corrosion may be discovered, it is often necessary to remove part of the corrosion product without interfering with the surface of the lead. This can usually be done satisfactorily by working under a low-magnification microscope and prising or picking out the corrosion product with a mounted needle. With care, sufficient corrosion product can be removed, without damaging the lead, to enable the type of attack to be decided. The main types to be watched for are:—

(*a*) General attack of the metal, with no preferential corrosion at the crystal boundaries. The only evidence of the crystal structure will frequently be patches of light and shade due to the orientation of different crystals. In many cases even this is missing, and the corroded metal appears as a severely roughened, homogeneous mass.

(*b*) Intercrystalline attack, in which the lead crystals themselves are comparatively undamaged, but the crystal boundaries are eaten away, the attack being often so pronounced that individual lead crystals are completely undermined by corrosion products and can be lifted out whole on the end of a needle.

(*c*) Pitting. The pits may be shallow and saucer-like, or steep-sided and perhaps undercut. Similar distinctions may apply to any furrows which appear to be corroded.

(*d*) Any other peculiarities. Occasionally an abnormal type of attack may be met, and its very character will point to the cause of the damage.

When this work is being done, it is usually convenient to collect representative samples of the corrosion products, which are reserved for chemical analysis.

(5.2) Analysis of Corrosion Products and Duct Water

A representative sample of the corrosion product is analysed. The determinations generally to be made are: (1) Chloride. (2) Sulphate. (3) Lead. (4) Carbonate (occasionally).

Qualitative tests are made for peroxide (with Trillat's reagent) and nitrite. A test for peroxide will occasionally give a yellowish-green coloration instead of the pure blue normally given by peroxide. In all such cases a subsequent test has shown nitrite to be present.

In addition to the examination of the lead specimen, it is usual to make an examination of the water from the duct line if this is available, since any deductions to be made from the composition of the corrosion product must be based on certain assumptions about the composition limits of the water. Soils are not often examined, since the cables are laid in ducts, but occasionally it is necessary to test specimens of mud which has been removed from the duct line.

Water analysis generally comprises determination of the residue (total and inorganic), chloride, sulphate, car-

bonate, silicate, nitrate, nitrite, ammonia, sodium, calcium, and magnesium. A colorimetric test for *pH* value is also made. This is not a standard type of water analysis, such as is made in the case of drinking or industrial waters, but from the results it is to some extent possible to predict the corrosiveness of the water, and also in many cases it is possible to state its source, thus making it simple to stop the infiltration.

(5.3) Diagnosis from Chemical Tests

When the tests and examinations described in Sections (5.1) and (5.2) have been made, Table 3 may be used as a guide to diagnosis. The conclusions expressed in this Table are based on the authors' experimental observations, although they include much that has been accepted for a long time. When the present authors commenced their work, however, it was found that, although many others had published their conclusions as to the phenomena observable after corrosion under specific conditions, such conclusions were not in general supported by available experimental evidence.

(5.31) Character of attack on the metal.

The present criteria were first of all developed from laboratory observations of test pieces corroding under known conditions, the general method used being to immerse extruded lead specimens in a number of liquids which were either water samples collected from cable conduits, etc., or were artificially-prepared liquids of similar composition. In each case some samples were allowed to corrode without electrical stimulation, and other samples were made anodes in electrolytic cells, the cathodes also being of lead. Potential differences of 0·1–0·25 volt were generally used, these being typical of the potentials experienced in the field. It was found that, as a general rule, the electrolytically corroded specimens suffered intercrystalline attack, whereas the specimens which had not been subject to electrolytic

Table 3

Diagnosis of Cause of Sheath Failure

(i) *Character of attack*

Indicating electrolysis	Indicating chemical corrosion
Steep-sided pits, sometimes undercut, and long corroded furrows in the metal. Pits may be distributed at random, or may run in straight lines along the cable	A more uniform attack, in which the crystal boundaries are not subjected to preferential damage
Visible fissures between the crystal grains in the metal to the extent that it is sometimes possible to detach individual grains	Corrosion which tends to take place uniformly over the surface of the metal, and, if it causes pits, does not form undercut ones, but rather the shallow saucer-like kind

(ii) *Composition and character of corrosion product*

Indicating electrolysis	Indicating chemical corrosion
Transparent watery crystals of corrosion product, or white needles	Opaque, powdery corrosion product, or red crystalline litharge
Analysis shows a composition rich in chlorides and sulphates	The corrosion product is substantially lead carbonate, basic carbonate, or lead oxide
In many cases lead peroxide is to be found, using Trillat's reagent	The presence of lead peroxide is unusual, but nitrites may be detected

(iii) *Composition of the earth water*

Indicating electrolysis	Indicating chemical corrosion
Clean neutral earth waters containing only normal amounts of chlorides, carbonates, and sulphates, and substantially free from organic matter, ammonia, or other forms of nitrogen	Acid or alkaline waters, outside the usual range of 6·5–8·5 *pH*. High chloride concentration, presence of ammonia, nitrates, or nitrites; presence of organic matter, particularly in a colloidal form Waters containing sewage or farmyard drainings are very harmful

stimulation did not do so. Two typical specimens are shown in Figs. 2 and 3 (see Plate 1, facing page 688). This observation was then checked by examining specimens taken from localities in the field where the electrical conditions were fully known. The findings arrived at in the laboratory were completely confirmed.

From these observations the opinion has been formed that electrolysis tends to produce an attack which is characterized by steep-sided pits and craters in the metal, damaging a relatively small proportion of the whole exposed surface as shown in Fig. 4 (see Plate 1), whereas chemical corrosion tends to be more widespread and uniform in nature. Electrolysis is also prone to attack the metal preferentially at the crystal boundaries, leaving substantial fissures between the crystals. This does not imply that electrolytic attack confines itself to the crystal boundaries, but means that the rate of penetration is much greater along them. This phenomenon can be seen to perfection on some cable sheaths which have failed by electrolysis, and in which individual lead grains have been so undermined that they can in many cases be removed almost undamaged by the gentlest leverage with a needle.

In cases of "burn-outs" (see Section 4.5) the cable sheath may be perforated by a steep-sided hole, but the centre of the hole instead of containing the corrosion product is nearly always full of spongy lead. Fig. 5 (see Plate 1) shows a typical specimen of such a fault, the cause of which is not always recognized.

(5.32) Composition of corrosion products.*

When corroded cables are examined one may be occasionally found in which the corrosion product consists of a hard, bright-red mass. This sometimes occurs in pockets and may actually perforate the cable, but is more generally spread fairly uniformly over patches of the surface. In this case it does not stand appreciably proud of the surface and may, unless cleaned, be mistaken for undamaged metal. When crazed, it is very similar to a fatigued lead sample, as the surface often acquires a grey colour indistinguishable from that of lead. Fig. 6 (Plate 2) shows cable-sheathing with this corrosion product in pockets.

Analysis of this substance has shown it to be almost pure lead monoxide (PbO)—not red lead (Pb_3O_4)—and it has never yet been associated with a definite case of electrolysis. It has usually been found in cases where the water is slightly alkaline, such as, for instance, in concrete manholes. It can definitely be produced by corroding lead with lime water, and with fresh portland cement (Fig. 6, see Plate 2).

When an actual perforation is found filled with this material, one must be careful not to confound an extrusion fault with a corrosion fault. Very occasionally, sheath faults are met in which the same oxide is present in a similar physical form and is actually a dross inclusion which has been trapped between two lots of metal in the lead press.

Lead peroxide.—There has been considerable discussion as to the significance to be placed on the presence or absence of small amounts of lead peroxide (PbO_2) in the corrosion products.

* The relevant compounds of lead are briefly described in the Appendix.

Lead peroxide is usually tested for with Trillat's reagent (tetramethyl-diamino-diphenylmethane acetate). This test depends on the peculiar oxidizing properties possessed by lead and manganese peroxides, but not by sodium, barium, magnesium, etc., peroxides. Since manganese peroxide is not likely to be present on a cable sheath, the test may be regarded as specific for lead peroxide. In connection with the use of this test, two points must not be overlooked:—

(*a*) Red lead (Pb_3O_4), which as normally prepared cannot contain lead peroxide, will itself give a positive reaction for lead peroxide. This is presumably due to the action between red lead and acetic acid. It has also been shown by numerous observers* that red lead can be produced when lead corrodes in aqueous solutions without external electrical stimulation. Other observers have testified to the formation of red lead by the corrosion of lead in lime water. Some of these may have mistaken the bright-red form of lead monoxide for red lead, but it can nevertheless be demonstrated that a corrosion product giving a positive reaction for lead peroxide can be obtained by corroding lead in lime water. It seems at least possible that this product is calcium plumbate ($CaPbO_3$).

(*b*) There is a purely chemical way in which lead peroxide can (theoretically) be obtained as a corrosion product. It has been shown that the corrosion of lead under certain circumstances can produce hydrogen peroxide (H_2O_2) as a corrosion product. It can readily be demonstrated that lead hydroxide $Pb(OH)_2$ is a product of corrosion in some circumstances. From these two materials it is possible to produce lead peroxide. There are therefore two ways in which a material reacting as lead peroxide can be formed solely by chemical corrosion.

On the other hand, the formation of lead peroxide during the electrolytic corrosion of lead is not an invariable matter, but one which depends on the exact circumstances. Experiments were made, in various liquids resembling natural soil waters, to see whether current density and anode potential had any bearing on the matter. As would be expected, it was found that at the lower current densities lead peroxide did not form readily, and that at higher densities it was formed in increasing quantities. The chemical composition of the electrolyte also had a bearing on the question, peroxide forming less readily in the presence of abundant chloride than when it was absent. To take a specific case, natural earth water, rather high in chloride, was tested. At current densities of $1\cdot7$–$5\,\mu A$ per cm^2 no peroxide was found, the corrosion product consisting principally of chloride ($PbCl_2$) and carbonate ($PbCO_3$). At $6\cdot7\,\mu A$ per cm^2, however, the anode was covered with a chocolate-brown deposit of lead peroxide.

With regard to the use of the peroxide test as an indication of electrolytic attack, the position appears to be: (1) A positive reaction for lead peroxide does not necessarily mean that electrolysis has occurred, but may be regarded as pointing in that direction. (2) A negative result is no evidence at all that electrolysis has not occurred.

Lead chloride.—Several years ago Haehnel† pointed

* See Bibliography, (17). † *Ibid.*, (2).

out a relationship between the cause of corrosive attack and the chloride content of the corrosion product, stating, for instance, that "... in no case have I found more than 1 % combined chlorine in a corrosion product which was not the result of electrolysis," and "the product of an anodic corrosion is characterized by a large amount of lead chloride."

Numerous analyses of corrosion products from cables have been made, and it can be said that in all cases in which the corrosion product contained more than 5 % combined chlorine the electrical field tests left no doubt at all that current was ionically leaking from the cable sheath to earth at the points in question. Also, in confirmation, in those cases in which the corrosion products contained less than 5 % chlorine the electrical field tests failed to establish that the corrosion was electrolytic.

The following data are typical of these cases:—

Chlorine content of waters, 78–504 parts per million
Chlorine content of electrolysis products, 7·9 %–19 %
Chlorine content of non-electrolysis products, < 2 %
pH values of waters, 7·3–8·5

Laboratory tests made under controlled conditions have confirmed these findings. In a typical case, water was collected from a duct line and allowed to corrode lead plates, (*a*) by chemical action only, (*b*) by electrolysis at 0·25 volt between lead plates. The corrosion products taken from the pits were analysed, with the following results: (*a*) chemical corrosion, 1 % chlorine; (*b*) electrolysis, 9·2 % chlorine.

Since the electrolytic corrosion products of lead are characterized by a large amount of chloride, present as lead chloride or lead chlorocarbonate ($PbCl_2 . PbCO_3$), experiments were made to determine whether, in the absence of electrolytic conditions, these compounds were stable in the presence of typical earth water.

The tests made it clear that naturally-occurring compounds of lead and chlorine are not stable under conditions of simple immersion in ordinary earth water, but are stable when the chloride content of the water is high enough. This is confirmed by the writings of Lacroix and others,* who have found that lead chlorocarbonate is formed as the result of chemical corrosion of lead in sea water. A further series of laboratory tests was then undertaken in which corrosion products having a high chloride content were formed by passing current between electrodes immersed in water simulating natural earth water. The current was then disconnected and the anodes examined after standing in the electrolyte for various further periods. The results given in Table 4 confirmed the view that, in waters of normal composition, lead corrosion products rich in chloride are not stable but tend either to be washed away or to be converted into more stable, but less soluble, salts. It is therefore clear that lead corrosion products rich in chlorides are incompatible with chemical corrosion in earth waters of typical composition. The behaviour of the sulphate radicle is not so clear and requires more investigation.

This theory has received unexpected field confirmation in the case of a number of cables at one spot which had been corroding electrolytically for many years, giving corrosion products with 8 % to 19 % chlorine. Quite recently one of these cables broke down and on examination the corrosion product was found to contain only 2·7 % chlorine but 18·2 % sulphate, being in fact totally different from anything which had previously been found in this area. Some 7 months before the occurrence of this latest fault, electrical alterations had eliminated stray currents from the particular length in question. It is evident that over a period of years the cable had been corroding by electrolysis, giving the usual type of corrosion product, but that for 7 months the electrolytic stimulation had ceased and the chlorine was then slowly washed out of the corrosion product by the water in the ducts.

On the evidence available it seems that the presence of corrosion residues rich in chlorides can be taken as indicating that the corrosion has been caused by electrolysis. The chloride content of the water must, however, be borne in mind.

Table 4

COMPOSITION OF PRODUCTS OF ELECTROLYSIS

	Percentage of chlorine in corrosion product	
	Normal earth water	Earth water with sulphate addition
At end of electrolysis period ..	12·0	22·2
After standing for 1 month ..	2·4	6·7
After standing for 3 months ..	2·6	4·2

(5.4) Importance of Local Conditions

Instances frequently occur where sheath corrosion cannot be explained without reference to unusual local conditions. Fig. 7 (see Plate 2) shows the paper core of a cable exposed over an area of several square centimetres; this was caused by the local condensation of moisture on the top of the sheath at a spot where ice-blocks were habitually placed on the pavement above the conduit. The corrosion product consisted of masses of basic lead carbonate. The cable in this case was contained in an iron pipe which was otherwise dry. Cables so laid are regarded as relatively immune from corrosion, but trouble has recently been experienced where a type of "white lead" (acetic acid) corrosion has occurred immediately adjacent to spigot and socket pipe-joints. It has been traced to the development of a high degree of acidity in the jute packing of the joint.

(6) FIELD TESTS

(6.1) Measurement of Longitudinal Current Flow

Fig. 8 shows the equipment regularly used in this country for measurement of the current circulating in telephone cable sheaths. The portable battery and regulating resistor enable this current to be diverted

* See Bibliography, (19).

through the ammeter. A sensitive pivot galvanometer indicates when this diversion is complete.

(6.2) Measurement of Current Discharge from the Endangered Structure

As electrolytic corrosion is due to current passing from the metal sheath to earth by an ionic path, the most

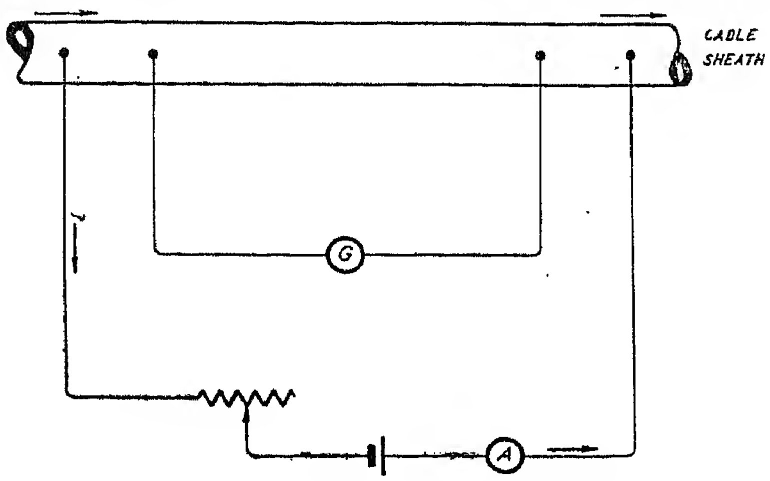


Fig. 8.—Post Office tester No. 36.

useful measurement is that of the surface current-density at the point where the current is being discharged.

(1) Haber's method utilizes two non-polarizable electrodes buried in the earth at a known separation and joined through a milliammeter. It enables a measurement to be made of the mean current density in the earth adjacent to the pipe or cable, but is open to the objection that burial of the measuring electrodes disturbs pre-existing conditions to some extent.

(2) Determination of the resistivity of the soil and complete exploration of the stray-current paths by the use of small non-polarizable electrodes placed at the bottom of a hole bored in the earth adjacent to the pipe or cable has been studied in Switzerland.

(3) A surrounding cylindrical electrode of identically the same material as the pipe wall or cable sheath, to which it is joined through a milliammeter, has been used in Germany to measure the current leaving a restricted area.* The electrode must be fitted before a measurement can be made, and this is a serious disadvantage.

(4) The reliability and usefulness of the McCollum earth-current meter† have been demonstrated under a variety of field conditions in the U.S.A. Although it has not been used extensively in Europe, it is probably the most facile and reliable of the existing methods. Excavation of a trench or borehole to accommodate the four-electrode contactor is necessary.

(5) The three-electrode, differential method, originally

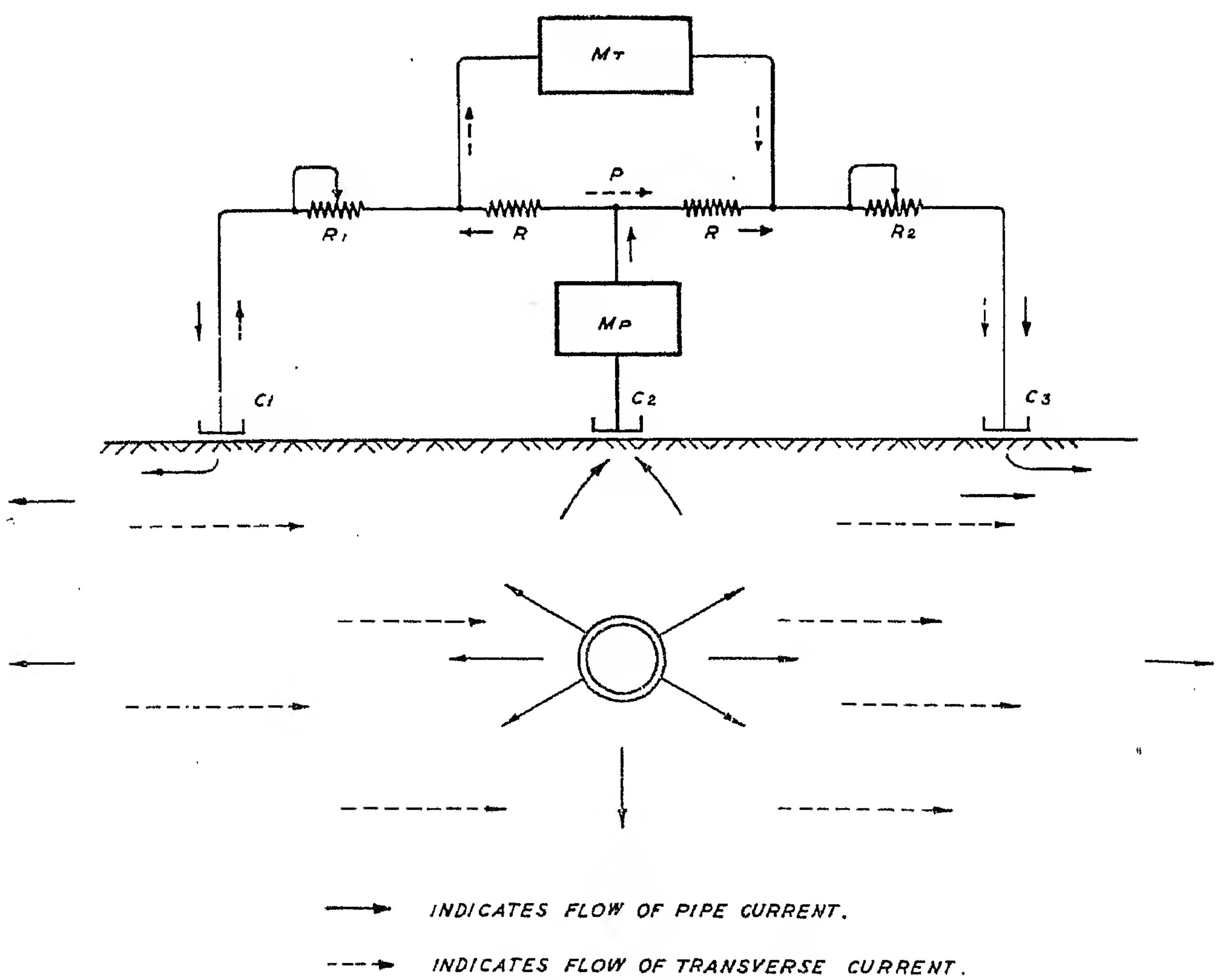


Fig. 9.—Schlumberger's differential method of measuring earth current.

(6.21) Directly-buried pipes and cables.

The following methods are in use for the measurement of the radial current flow from a pipe or cable buried directly in the earth.

due to Schlumberger,‡ may be used to measure independently the earth current terminating in a buried pipeline or cable and that flowing past the pipeline and

* See Bibliography, (7). † *Ibid.*, (4). ‡ *Ibid.*, (5).

independent of it. Excavation of the ground is unnecessary, the equipment comprising three non-polarizable copper-sulphate electrodes which are placed on the surface of the roadway, as shown by C_1, C_2, and C_3 in Fig. 9. C_2 is immediately over the pipe and the other pair equally spaced by about 15 ft. from it. M_T and M_P are centre-zero microammeters of 10- to 15-μA range which can be shunted if necessary. Cutting a battery in and out of circuit in place of M_P enables the value of R_1 or R_2 to be adjusted until the resistance between the ground under C_1 and the point P is the same as that between P and the ground under C_3. The reading of the meter M_P will then depend entirely on the interchange of current between the buried pipe and the earth. In the presence of transverse current only, however, no current will flow in the pipe meter M_P, but a reading will be obtained on the transverse meter M_T.

The readings of the pipe meter, together with the

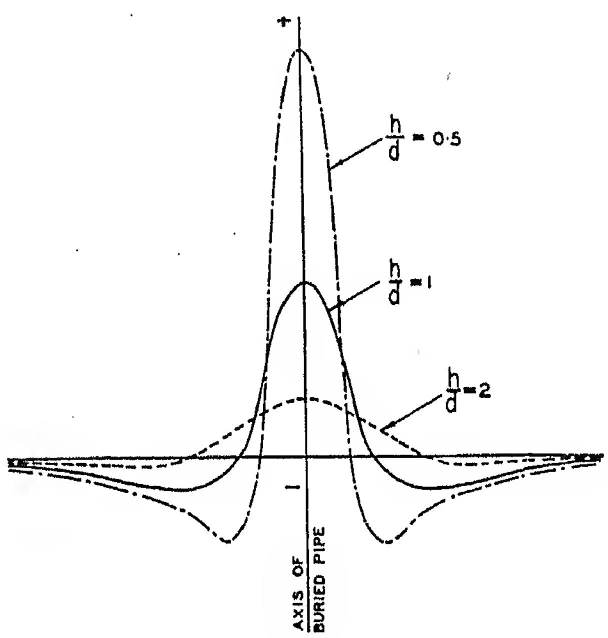


Fig. 10.—Three-electrode differential method: variation of potential with movement of measuring system.

measured soil resistivity and the pipe depth, can be translated into terms of milliamperes per foot run interchanged between the pipe and earth. The readings of the transverse meter can be translated into the earth potential gradient perpendicular to the line, or, with the resistivity of the earth, into terms of microamperes per square foot of transverse earth current.

The method has recently been developed by Gibrat* in France and is attracting considerable attention in Europe. By moving the electrodes about, it can be used to locate buried pipes which are interchanging current with the earth. Fig. 10 indicates the variation in meter reading as the electrodes are moved across the line of a pipe. Using a sensitive potentiometer arrangement in place of the pipe meter, Gibrat claims to be able to measure a current interchange almost down to 1 milliamp. per foot run.

(6.22) Cables enclosed in conduits.

The above methods fail when cables are enclosed in conduits. In this case the measurement required is that of the current interchange between the cable sheath and the soil water, silt, etc., *also in the conduit*. It has been the practice of the Post Office to deduce this interchange from simultaneous measurement of the sheath current at two points a short distance apart. Such points are usually where the cable passes through adjacent jointing-boxes normally separated by $\frac{1}{10}$ mile. At each of these a measuring instrument is connected in shunt across a length of cable sheath of known resistance, the connections to at least one of the instruments being extended so that both may be located at the same place.

Owing to the rapidly fluctuating nature of the stray currents from street-railway and other traction systems, it is essential that some form of photographic recorder should be employed for the simultaneous registration of the current at the two points.

Further, as the resistance of the maximum length of cable which can be included between a pair of the testing connections may not exceed 0·00025 ohm, and electrolysis occurs with sheath currents of less than 100 mA, the measuring instrument must be capable of giving a reasonable deflection when 0·01 mV is applied to its terminals. Also, as it has to be used in the street, it should be readily set up and not affected by a certain amount of vibration. It has been found that a galvanometer consisting of a loop of extremely thin aluminium foil suspended between the poles of two permanent magnets fulfils these requirements. The loop has a resistance of between 5 and 7 ohms. As it is extremely light its deflections are aperiodic; and, being sealed in a glass cell, it is not disturbed by draughts or air currents. The two permanent magnets are arranged as shown by Fig. 11, so that when current is passed round the loop both limbs are deflected to the same side. The loop is supported by its own stiffness against movement in a plane at right angles to this. For the purpose of obtaining a continuous record, an image of a small part of the loop may be projected by means of a filament lamp on to a photographic film.

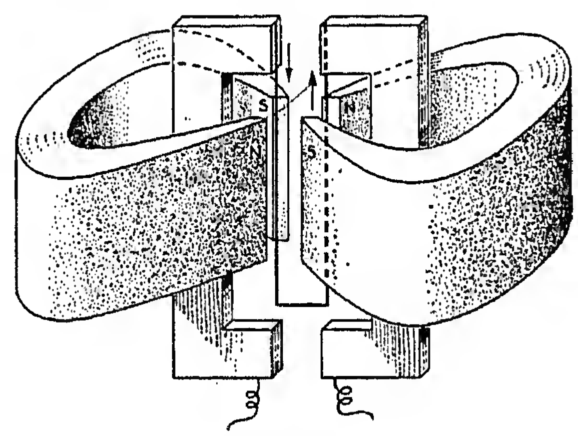


Fig. 11.—Loop galvanometer: the arrangement of the magnets and the loop in its normal position.

A picture of the complete equipment developed for use in detailed field investigations was shown to The Institution in 1934 by Captain B. S. Cohen,* and a similar picture was recently shown to the American Institute of Electrical Engineers by one of the present authors.† With this equipment the double record is taken on a film 62·5 mm. wide, driven at a speed of between 3 and 10 cm. per min. by a small 6-volt motor.

* See Bibliography, (8).

* See Bibliography, (18). † *Ibid.*, (15).

This motor and the projection lamps for the galvanometer are supplied from portable batteries, the whole equipment being easily transported.

A typical record showing the current at two points on a telephone cable sheath was also reproduced in the paper just referred to.

(6.3) Deductions as to the Source of the Sheath Current

Records obtained in the manner described give very clear indications as to the origin of the sheath current. Stray return current from heavily loaded tramway systems fluctuates very rapidly. With less heavily loaded lines the changes resulting from the movement of individual cars become apparent, as shown by Fig. 12 (see Plate 2).

When cable-sheath current measurements are made by highly sensitive instruments such as those described, it is often found that a small steady current flows after all suspected sources of earth-current leakage have been made electrically dead. Experiments have shown, however, that such effects may be due to the discharge of an electrolytic cell formed between two parts of the cable system, or between the cable system and the rails of the traction system. The earth forms the electrolyte. During periods when the leakage currents passing to and from the ground are large, a forming process takes place. When these currents cease, the cable sheath discharges in a manner analogous to the discharge of a secondary cell. The phenomenon may persist for several hours.

(6.4) Potential-difference Measurements

Deduction of the average intensity of current discharge from the difference between the values of the longitudinal sheath current at two points depends on an assumption of a likely value for the area of the cable sheath actually in contact with soil water, silt, etc. The method is also open to the objection that it gives no indication of the existence of "hot spots" where the current discharge is localized. Some telephone authorities, therefore, still rely on measurements of the p.d. between the cable system and earth, although such measurements do not serve as a complete criterion of the extent to which the former is endangered, as the current discharge is determined also by the resistance of the discharge path. Some form of lead "bob" or cup resting on the manhole floor is frequently used for these measurements. A voltmeter having a resistance of 4 000–5 000 ohms per volt is necessary owing to the high contact resistance, but variations of contact potential are such that readings within the range $\pm 0 \cdot 1$ volt have to be neglected.

Serious corrosion occurring with potential differences smaller than this has led to the field use of calomel half-cells* as reference electrodes in both Great Britain and the United States. In this country, saturated potassium chloride was utilized and the electrodes were prepared in the Post Office Research Laboratory and then kept under observation for some time to confirm that they remained stable. For field use two electrodes were mounted in a box and insulated from shock and temperature-changes by rubber and cotton wool. Contact with the water in the duct was made by extending the usual glass connecting bridge with a rubber tube filled with saturated potassium-chloride solution and terminating in an exploring nipple of ebonite, which was filled with a stiff jelly of agar-agar and the duct water concerned. In this way the consideration of junction potentials was reduced to a minimum. The exploring nipple was tied to a set of cane rods and pushed up the duct containing the cable or up a vacant duct alongside it. In America the Bell Telephone Laboratories constructed a small calomel half-cell which could be pulled complete through the cable duct. A supporting strip of lead served as a mechanical protection for the electrode and also enabled the "rest" potential of lead with respect to the electrode (i.e. the p.d. that would exist between the electrode and the cable sheath if there were no

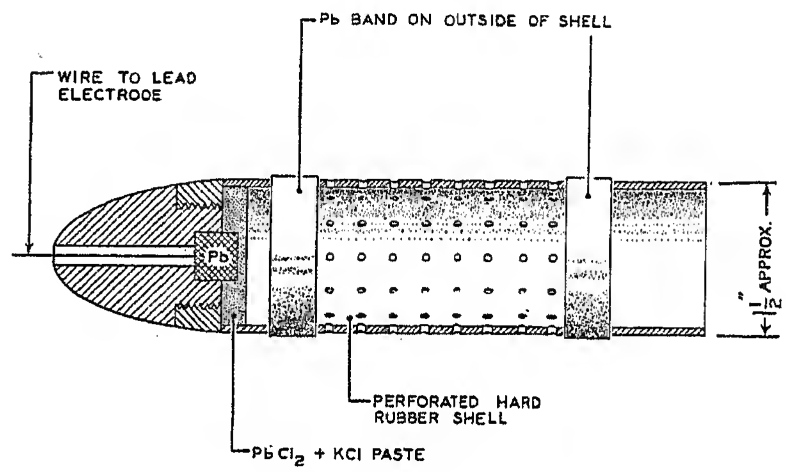


Fig. 13.—Lead-chloride non-polarizing electrode.

current interchange between the latter and the water in contact with it) to be determined for any particular environment.

On both sides of the Atlantic attention has subsequently been given to the construction of simpler types of electrode of sufficient stability for the measurement of potential differences of less than 100 mV. Fig. 13 shows a lead-chloride electrode developed by the Bell Telephone Laboratories. It consists of a perforated hard-rubber shell filled with an agar-agar gell containing saturated lead and potassium chlorides together with glycerine to minimize drying-out of the agar. The Post Office Research Laboratory, on the other hand, have experimented with the field use of the copper-copper sulphate electrode shown in Fig. 14.

The last three electrodes described are suitable for pulling along a cable duct and, therefore, for cable-duct and manhole exploration work. With the Post Office form of calomel electrode the same result can be obtained by movement of the exploring nipple. Valuable information can be obtained by the use of such electrodes. For example, Fig. 15 shows the variations in potential recorded when a calomel half-cell electrode was pulled through a cable duct in New Orleans. The potentials recorded indicate areas where the environment was

* The calomel half-cell or calomel electrode is an accepted reference standard of potential. The instrument is usually made in tubular form, a pool of pure mercury at the bottom of the tube being covered by a layer of pure mercurous chloride (calomel). The electrolyte on the top of this is standard (usually "normal") potassium-chloride solution saturated with calomel. Contact with the mercury is made by a platinum wire fused through the glass, and the other contact is made through a liquid (potassium chloride) bridge. The "absolute" potential of the normal calomel electrode is considered to be $+ 0 \cdot 560$ volt at 18° C.

negative to the cable, as well as those where it was positive. The existence of these areas would not have been disclosed by any measurements confined to the manholes. Their presence is of more than theoretical importance, for, as indicated above the potential curves

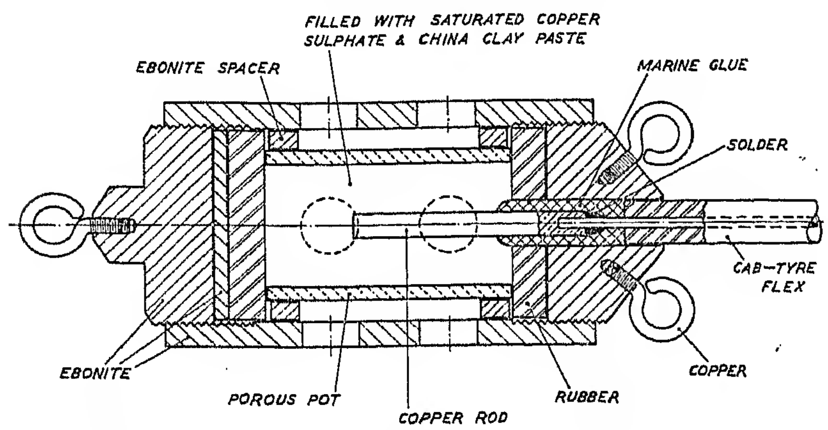


Fig. 14.—Non-polarizing copper-sulphate electrode.

of Fig. 15, corresponding parts of the cable sheath were heavily corroded while others were unharmed.

Corrosion problems now confronting engineers interested in the maintenance of such underground plant as telephone cables indicate that increasing attention must be given to the possible change of conditions occurring over a few yards of conduit. Such changes have an importance which was not suspected a few years ago.

(7) METHODS OF PROTECTION

(7.1) Choice of Sheathing Material

(7.11) Lead versus lead alloys.

The hope has been expressed from time to time that some lead alloy could be discovered which would be less readily corroded than either pure lead or any of its alloys which are at present in use. It is well known,

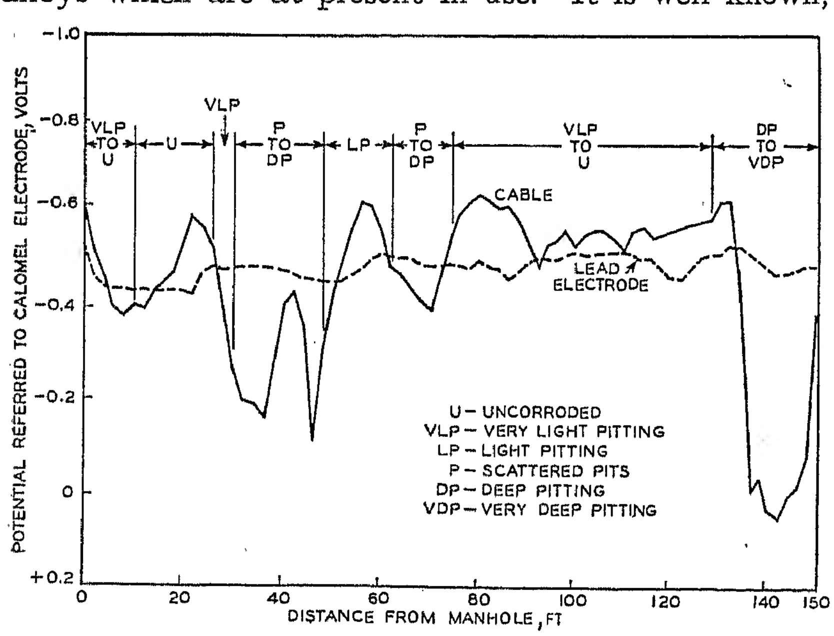


Fig. 15.—Underground-cable potential measurements.
(Reproduced by permission of the Bell Telephone Laboratories.)

for instance, that the addition of copper to lead which is to be used in certain chemical plant will materially increase its resistance to corrosion, and tellurium additions have recently been claimed to give similar immunity. But although numerous tests have been made on all the alloys available, and on a number which are not in commercial production, no one alloy has been found which is superior to pure lead under all conditions of exposure. Under certain conditions which resemble those occurring naturally, alloys containing tin have been found to be slightly superior to lead, but under other conditions which also resemble service these alloys are definitely worse than lead. The question is not so important as might at first sight be imagined. It is a fact that, although no alloy has been found which can be regarded as better than lead, the differences between the metals are so small that they are generally insignificant compared with, say, differences in mechanical properties. Corrosion resistance can therefore to a considerable extent be disregarded.

The following order of corrosion resistance under normal field conditions of some of the lead alloys in common use in this country is put forward with considerable hesitation, as so much depends on the actual testing technique. It does, however, represent the authors' present views on the matter.

Lead.
Lead-antimony-cadmium (B.N.F. ternary alloy No. 1).
Lead-tin (3 %).
Lead-antimony (0·85 %).
Lead-tin-cadmium (B.N.F. ternary alloy No. 2).
Lead-antimony (0·5 %)-tin (0·5 %).
Lead-tellurium (0·06 %).
Lead-tin-cadmium (B.N.F. ternary alloy No. 3).

The first material listed is the best, and the last is the worst.

(7.12) Non-metallic sheathings.

The question of replacing lead altogether by one of the modern plastic materials has been frequently discussed by telephone administrations. There are various materials which are, or could be made, mechanically suitable. They are mostly of the thermoplastic, synthetic-resin type—cellulose acetate, vinyl, styryl, and acrylic acid resins are those most generally suggested. These are all fairly expensive materials, costing at present up to about three times as much per cubic foot as lead. Actual experience of paper-core cables sheathed in plastic material is at present rather meagre, as there are technical difficulties in the way of making up the cable. But the information available shows that some, at least, of the suggested compounds are not sufficiently impermeable to water to make them suitable for this purpose without the addition of a thin metallic sheath. It is reported from the Continent that a cable has been developed with a satisfactory cellulose-acetate sheath, but no details of it are known.

Experience over a number of years with paper-cored, lead-sheathed, submarine cables, which are protected on the outside by a special rubber covering, gives rise to the hope that certain organic materials may be found which will keep water out satisfactorily. Whether or not these will prove to be economically practicable is an open question.

(7.2) Protection against Chemical Corrosion by Use of Cable-sheath Coverings

In a great many cases it is found necessary to protect the lead surface in some way. Protective coverings on

telephone cables are of two main types: (*a*) Tape and compound. (*b*) Extruded rubber-wax mixtures.

(7.21) Tape and compound protection.

This is a generic term descriptive of the various methods of protecting a cable by dipping the cable in bitumen and wrapping it with bituminized fabric. There are many variants of this process. In the early days coal-tar pitch formed the basis of the compounds used, but nowadays petroleum pitches and blown asphalts are employed. Compound-protected cables are used more extensively by power engineers than by telephone engineers in this country.

For telephone cables, the present general practice is to use petroleum bitumen to cover the cables, which are then lapped with two layers of vacuum-impregnated bituminized hessian tapes. Observations some years ago led to the formulation of a specification for Post Office cables involving wrapping with two layers of bituminized paper and giving only the final wrapping with hessian. It has been found that paper-served cables retain their insulation to wet earth much longer than those which are covered entirely with fabric wrappings. It appears to be impossible to impregnate a textile well enough to make it permanently waterproof, possibly owing to the water passing along fine capillaries which do not fill with compound. In spite of the fact that the insulation resistance of a tape-and-compound-protected cable is of the order of a few ohms per mile only, this type of protection is regarded as the most satisfactory for general use in areas where some form of protection is necessary.

(7.22) Rubber-wax-protected cables.

There is one exception to the above generalization, however. If attempts are made to pull one tape-protected cable over another in a single duct-way there is likelihood that the tape may strip and block the way. Cables for use in these circumstances are therefore protected by a tough coating based on a mixture of rubber and vegetable wax. This material is extruded over the lead sheath at temperatures below 100° C. and is normally $\frac{1}{10}$ in. thick. These coated cables will draw in or over one another quite readily. The resistance to earth of the sheath of a rubber-wax-covered cable may be hundreds of megohms per mile when the cable is first laid, but after it has been submerged for a long time the value may fall to 1 or 2 megohms per mile. The covering would be more widely used, but for the cost.

(7.3) Protection against Chemical Corrosion by Use of Chemical Inhibitors

It is well known that certain chemical compounds when added to a saline solution, such as natural water, will materially reduce its corrosiveness to some metals. A typical example of this is the addition of minute quantities of sodium silicate to certain drinking waters to reduce their plumbo-solvency, i.e. to reduce the pick-up of lead during the passage of the water through lead pipes, and it seemed possible that a method of this kind could be applied to the protection of cable sheathing from chemical corrosion.

An extensive series of experiments showed that silicates, phosphates, chromates, molybdates, and tungstates, when added to corrosive earth waters, all had an inhibitory effect on the corrosion of lead. These substances appear to act by forming a tightly adherent film on the surface of the metal, which precludes further corrosion. This film is also very resistant to the passage of electricity, tests showing, for example, that with a current density of $4\,\mu A$ per cm^2 passing from a lead plate the voltage required rose from 0·04 to 0·15 volt in 7 weeks when electrolysis took place in water corresponding to natural earth water. When 170 parts per million (p.p.m.) SiO_2 (as sodium silicate) were added to this water it required 0·15 volt to maintain $4\,\mu A$ per cm^2 at the beginning of the experiment, and this rose to 0·7 volt in only 4 weeks. Other tests showed that when lead plates or cables were subjected to electrolysis at very low current densities the addition of sodium silicate

Table 5

INCREASED CABLE LIFE RESULTING FROM USE OF CHEMICAL INHIBITOR

Cases in which the (treated) replacement lengths had lasted longer than the original (untreated) lengths	203
Cases in which the treated lengths failed in a shorter time than the original lengths	33
Total failures of silicated cables, April, 1931–May, 1937	64*
Average life of original lengths ..	2·6 years
Average life of replacement lengths ..	> 3·8 years

* Includes 12 cases which cannot be dealt with elsewhere in this analysis owing to lack of data.

to the water definitely reduced the amount of pitting of the lead. This property is shared to some extent by most of the inhibitors mentioned above.

It is difficult to apply silicate treatment to cables which have already been installed, and such attempts as have been made have met with varying success. New lengths, however, are now lubricated for drawing-in with an emulsion of 12½ % sodium-silicate solution (containing about 20 % SiO_2) in 87½ % petroleum jelly. From this emulsion, sodium silicate diffuses very slowly into the surrounding water and slightly increases its silicate content for a considerable time.

In 1931, following laboratory work, it was decided to make a field trial of the method, using silicated jelly on the replacement lengths of cables which had failed very rapidly as a result of chemical corrosion. An analysis of the life of 248 cable replacement lengths which had been treated with silicate was made in 1937. This analysis showed the results given in Table 5.

Quite apart from the inclusion of a chemical inhibitor, liberal application of a suitable lubricant as the cable is drawn into the conduit has considerable effect in retard-

ing corrosion. At least one American power company using bare, lead-sheathed cables in conduit has considerably reduced its corrosion trouble by attention to this point alone.

(7.4) Protection in Stray-current Fields by Increased Insulation Resistance of the Sheath

An imperfect wrapping surrounding the cable in an area where the latter is anodic may be disadvantageous, as it

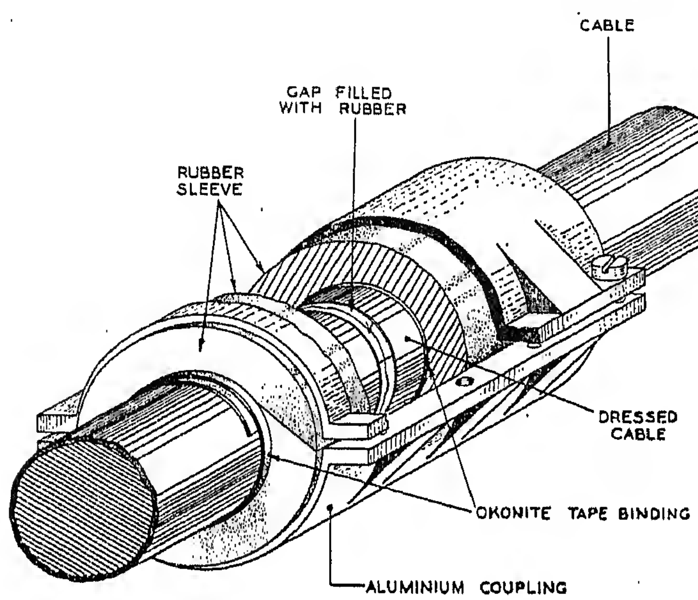


Fig. 16.—Insulating-gap details (part cut away).

will tend to concentrate a current flow at points where the lead sheath is exposed. Rubber-wax coverings have been used to a limited extent as a means of protection. The use of sheath wrappings and coatings of any form in areas where the cable is negative to its surroundings cannot be other than advantageous. In such areas protected cables are frequently used at crossings, etc.

In some towns in Italy, stray-current electrolysis from tramway systems, not subject to regulations, is very severe, and the cables are laid in bitumen-filled wooden troughs. In the same country over 2 000 km. of highly-insulated cable have been laid alongside the tracks of d.c. railways. These cables have two concentric lead sheaths separated by an inner sheath of rubber. In some cases a third lead sheath is put around an inner group of conductors at the centre of the cable reserved for important long-distance telephone circuits. The outer lead sheath is protected by several impregnated wrappings.*

(7.5) Protection in Stray-current Fields by Increased Longitudinal Resistance of the Sheath-current Path

Insulating joints have been extensively used in pipe systems in many countries. Insulating gaps in telephone cable sheaths are not generally liked by telephone administrations, but in Great Britain the protection of a number of telephone cables has been sought by their insertion at frequent intervals to prevent the flow of stray current along the cable sheaths. The success obtained has been due in part to the development of a type of insulating gap which could be easily made and which, with no subsequent attention, has given no cause of failure due to penetration of moisture to the cable conductors. The insulating gap is shown in Fig. 16. The break in the lead sheath is filled level with rubber or other insulating material, and one or more tight layers of " okonite " tape are applied over this and the sheath before the split rubber muff is fitted and the whole clamped up.

As an example of the extent to which conditions may be improved by breaking the continuity of long cable sheaths, attention is directed to Figs. 17 and 18. These refer to a number of trunk telephone cables laid in earthenware ducts which for 4 miles were in the same road as a tramway. Fig. 17 shows the current formerly flowing in the sheath of one of these cables. Repeated failures occurred due to the discharge of this current to earth at various points between Manholes 23 and 14. Corrosion was particularly rapid between Manholes 15 and 14, where the cables were 0·4 volt positive to the

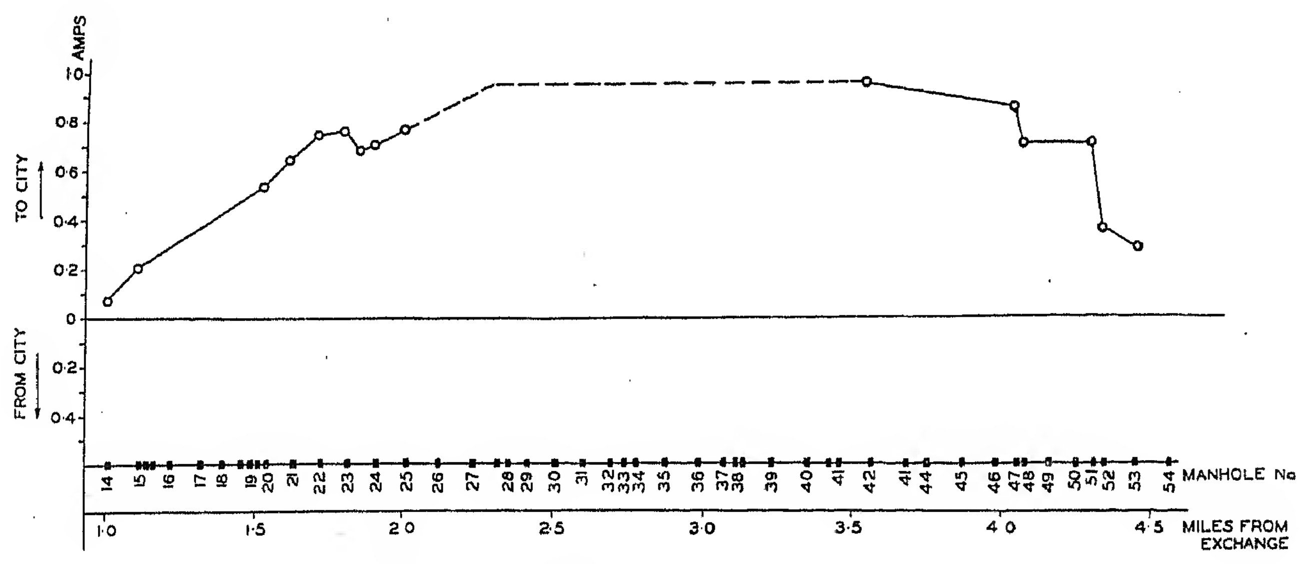


Fig. 17.—Current in cable sheath before insertion of insulating gaps.

duct, and many cables had to be replaced here. Insulating gaps were then inserted in all the cables at various points along the route indicated by the line diagram under Fig. 18. After this had been done the mean value of the sheath current at any point along the route measured during the period of heaviest tramway load nowhere exceeded 20 mA. A potential survey was then

* See Bibliography, (6), for Italian practices.

made of the whole route, giving the results shown by Fig. 18. The earth potential is in reality that of the immediate surroundings of the duct, and the variations shown are due to change of separating distance between the duct route and the tramway track. Each isolated length of cable takes up the mean potential of the portion of duct route in which it is located. After the work had been completed the maximum potential-difference between the cable sheath and the duct was of the order of 0·1 volt, although at the end of the route both the cable and its environment were at over 1·5 volts positive with respect to the adjacent tramway rail. The cables concerned were partially corroded through in many places before the first insulating gaps were inserted in June, 1934, but cases of subsequent failure have been rare and give a gratifying indication of the success of the method.

The case just described probably represents the best that can be done by the sole use of insulating gaps on a cable route very suitable for treatment in this way. Most of the isolated sections of cable were made so short that separation between the duct route and the tramway track, varying from close proximity at crossings, etc., to that when the duct route is under the footway, is one of the chief causes of potential difference between the sheaths and earth remaining with the completed scheme. No material reduction of these potential differences would easily be effected by the insertion of additional insulating gaps, unless new manholes were constructed for their effective location.

Where insulating joints are inserted in buried pipes it is desirable to insulate the pipe from its surroundings for some yards on the side of the joint where the tendency is for current to be discharged.

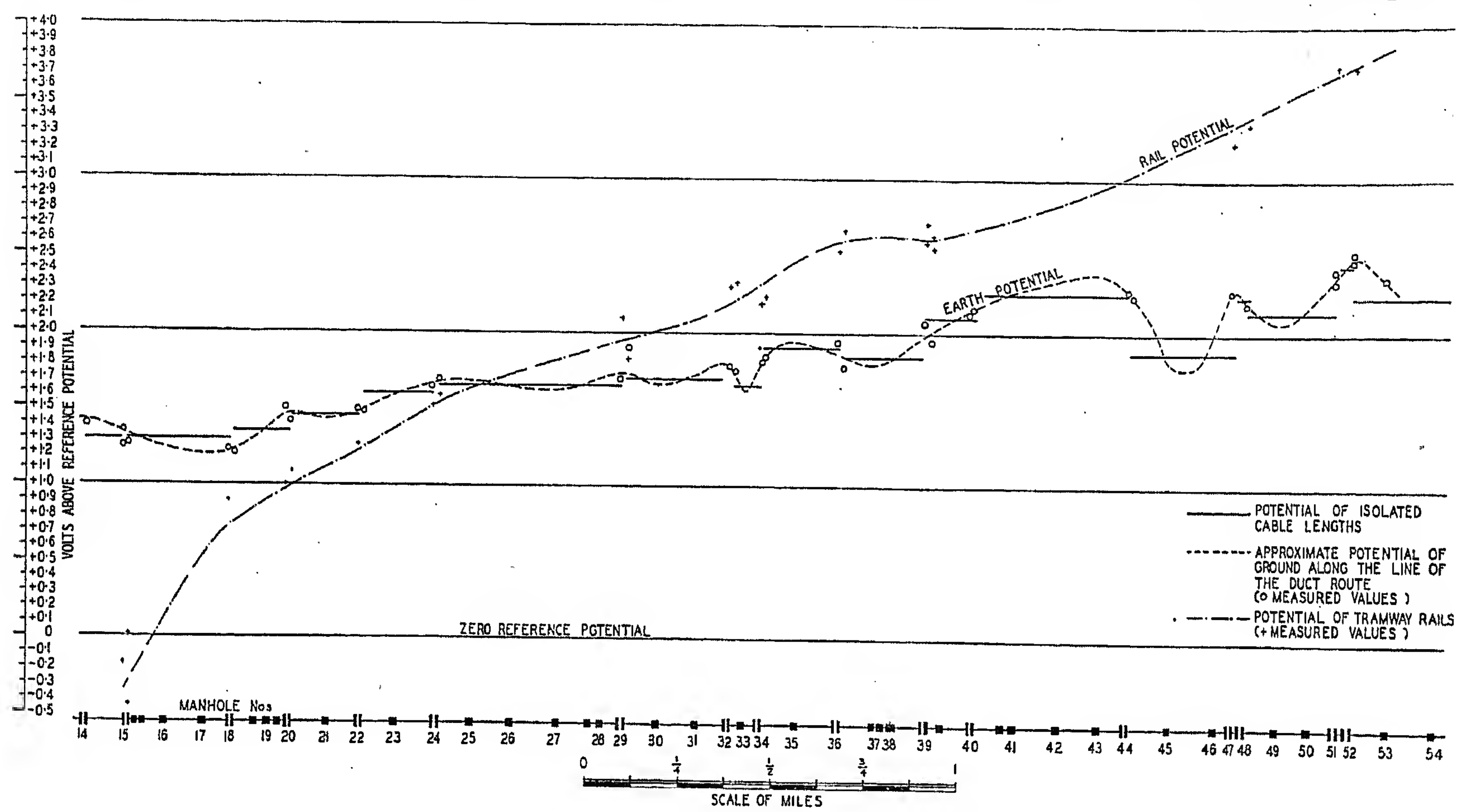


Fig. 18.—Potential of cable sheaths after insertion of insulating gaps.

(7.6) Protection in Stray-current Fields by Electrical Drainage

(7.61) Direct electrical drainage.

Direct electrical drainage, i.e. metallic connection of the endangered pipe or cable system to a point of low potential on the return traction system, has been extensively employed as a method of combating stray-current electrolysis in America and Australia. It has also been used in Europe, although the C.C.I.F.* only approve it with reservations. Conduction of the stray current away from one of a number of buried pipe and cable systems in this way, however, presents certain problems, as it alters the potential distribution between the drained system and all the others. In many cases the adoption of electrical drainage on the Post Office cable system would expose gas, water, and other pipe systems, etc. (often the property of the local authority), to greater danger from electrolysis. Wherever drainage has been adopted in other countries it has been found to necessitate a considerable amount of testing and costly periodic supervision.

In some cases these difficulties have been overcome by co-operative electrolysis surveys in the field and drainage schemes, including all the underground services. The measure of success attained by many of these schemes is due mainly to: (i) The separate drainage of lead cables and ferrous pipes. (ii) The design of drainage bonds according to definite principles.

The method of determining correct bond conductance has recently been described by Longfield.† With properly designed bonds the current drained remains small, whereas, when drainage schemes become competitive

* See Bibliography, (13).

† *Ibid.*, (10).

between various pipe-owners, substantial proportions of the return traction current may be transferred to the drained systems. The drainage of 200 A from large water mains was not uncommon.

In many cases, owing to a change in the distribution of the traction load, or to the closing-down of a substation to which a pipe is drained, the simple connection of a drainage bond would result in reversed current flow during certain periods of the day. To meet these conditions a rectifier is connected in the drainage circuit. In America and Japan, however, contactors have replaced the rectifiers in many places where high-conductance bonds are required. In Australia, a rectifier boosted by a rectified voltage from the electric supply has been provided where conditions required a low-resistance drain. Such a drain is not only unilateral, but provides a certain amount of cathodic protection which is independent of the track voltage.

(7.62) Controlled electrical drainage.

Recent Italian and—it is believed to some extent—Belgian practice has had for its aim the reduction of the potential of drained cable systems to small negative values with respect to their surroundings. The method has been frequently described in Italian publications* but not, so far as is known, in the English technical Press. The principles are illustrated by Fig. 19. In Fig. 19(*a*), PQ represents a section of cable laid in conduit parallel with a uniformly-loaded tramway track MN and isolated from the rest of the cable system by insulating joints which interrupt the continuity of the sheath at P and Q. AA′ represents the potential of the tramway rails with respect to the true earth potential, and BB′ that of the ground in contact with the conduit. The potential of the cable sheath is shown by CC′. Potential differences tending to cause current collection by the cable are represented by the area B′OC′, and those tending to make the cable discharge current by BOC. Fig. 19(*b*) shows the effect of making a direct connection between the cable and the rails at the point M. The cable becomes negative with respect to the ground throughout its length and tends to absorb, from its surroundings, current which is returned to the substation by the metallic connection. This connection may, however, endanger other buried pipes and cables, which will now have an increased tendency to lose current to the cable PQ. The danger is avoidable, in the first place, by the insertion of a resistance in the drainage connection, of such a value that the potential of the cable at P is adjusted to that of the ground immediately surrounding the conduit. The potential distribution is then as shown by Fig. 19(*c*). In the second place, the insertion of insulating joints in the

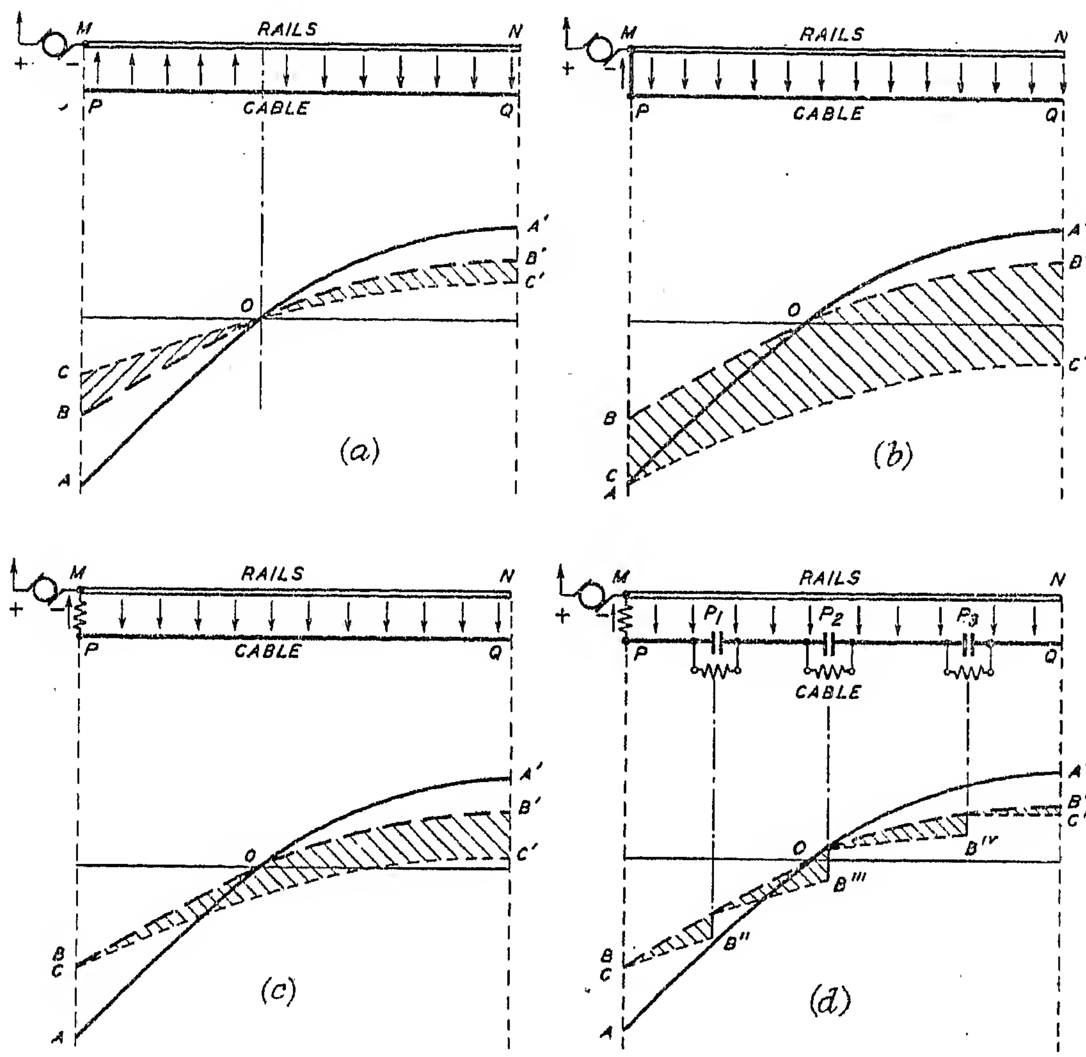


Fig. 19.—Potential variation of rails and cable-sheath.

——— Potential of tramway rail.
— — — Potential of ground about cable.
-·-·-·- Potential of cable sheath.
Arrows indicate direction of leakage currents.

* See Bibliography, (9).

cable sheath at P_1, P_2, P_3, etc., each of which is shunted by an appropriate resistance, enables the potential of the cable sheath to be brought to that of the ground around the conduit at various points along the route. The final result is shown by Fig. 19(*d*).

As an example of the application of this system, the telephone-cable network in Milan has been divided into 16 isolated sections by 343 insulating joints. Each of these sections is connected to the rails of the street-car system at one point by a drainage bond, and 354 shunted insulating joints regulate the potential of the cable within the sections.

(7.7) Cathodic Protection

To a certain extent the negative potential imparted to an electrically-drained cable system not only prevents electrolytic action by the stray traction currents, but also mitigates direct chemical attack by the surrounding soil waters. In some American towns the incidence of corrosion on telephone cable networks has increased with the closing-down of a tramway system to which the network was previously drained. Quite commonly, the cathodic protection previously given to such cables has been restored by connection of a source of small negative e.m.f. between the cable network and a suitable low-resistance earth-electrode system, such as the abandoned tramway tracks. Where a commercial a.c. lighting supply is available, the e.m.f. is obtained from a transformer and full-wave rectifier. Cathodic protection must always be applied to lead-sheathed cables with care, since the alkali which may be produced by the cathodic currents in certain environments is liable to give rise to severe chemical attack on the lead.

(7.8) Reduction of the Stray-current Fields due to Traction Systems

The leakage of current from the rails of traction systems is greatly increased by the presence of high-resistance rail joints. In countries where track maintenance was previously poor, considerable improvement in the conditions giving rise to the corrosion of adjacent pipelines and cables has resulted from the systematic measurement of the resistance of rail joints and the replacement of broken bonding connections.*

Other things remaining equal, the electrolysis danger which the tramway track constitutes to neighbouring pipe and cable systems depends on the maximum voltage-difference between two points on the track. Connection of an adequate number of negative feeders to suitable points on the track, as indicated earlier in this paper, is an effective means of reducing this voltage difference. Equalization of rail potentials at the points of connection of these feeders, as far as possible under all conditions of traction load, is, however, important if they are to be a benefit. Cases have been known to the authors where long negative feeders to distant parts of the tramway system were practically unloaded, the bulk of the traction current returning to the substation by way of one short low-resistance feeder. In certain places where substation negative earth-plates existed they have been disconnected as a first step in

* See, for example, Bibliography, (11).

Table 6

REGULATIONS GOVERNING STRAY CURRENTS FROM TRAMWAY SYSTEMS IN VARIOUS COUNTRIES

Country	Allowed voltage drop on track (1)	Allowed p.d. (in volts) between track and pipes (2)	Period of observation for voltage	Resistance of rail bonds:— In metres of rail	Resistance of rail bonds:— Percentage overall increase in resistance of track
Australia	2·2 V/km.	1·5 (pipes positive) 4·5 (pipes negative)	Maximum	—	—
Canada (Manitoba) ..	7 V overall 3 V/km.	—	Maximum hour	2·4	—
France (city)	1 V/km.‡	—	Average	—	20
France (suburban) ..	2 V/km.‡	—	Average	—	20
Germany (city)	2·5 V overall	—	Average	10	20
Germany (suburban) ..	1·0 V/km.	—	Average	10	20
Great Britain	7 V overall	1·5 (pipes positive) 4·5 (pipes negative)	Maximum	—	—
Holland	2 V/km.	—	Average	10	25
Hungary	2·5 V overall	—	Average (or 5 V for any 3 hours)	—	20
Spain	7 V overall	—	—	—	—
Switzerland	1 V/km.†	0·8 average 2·0 for any 4 hours	—	3	10
C.C.I.F.*	1 V/km.†	0·8	Average	3	10

* See Bibliography, (13).
† 1 V/km. for city, 1·2 V/km. in suburbs, and 1·4 V/km. in suburbs where ballasted track is used.
‡ Double the above values are allowed when pipes are more than 4 m. from the tracks.

stray-current mitigation. The replacement of tramways by trolleybus systems will, where the return conductor is insulated, result in a material improvement in the electrolysis hazard.

Table 6 gives the maximum track voltage-drop allowed in various countries, and any particulars specified as to the maximum resistance of rail joints.

(8) CONCLUSIONS

(8.1) Methods of Test

It is considered that in the great majority of cases of cable-sheath corrosion an accurate conclusion as to the reason for the failure can be formed from examination in the laboratory of the damaged sheathing, the associated corrosion products, and of water samples taken from the conduit in which the cable was lying. It is necessary, however, that all the available evidence should be taken into account.

No method has yet been devised for measuring the intensity of the current discharge from a cable enclosed in a conduit. The Post Office recording equipment, whereby the magnitude of the stray current at one point on the cable sheath is directly compared with its magnitude at another, has been found to give the required information in many cases of stray-current electrolysis. It is likely, however, that, under conditions that may arise in the future with greatly reduced stray-current fields, useful information will only be obtained from measurements related to non-polarizable electrodes capable of being pulled through the conduit. It is probable that the use of these electrodes will be developed.

(8.2) Methods of Protection

The non-metallic cable sheath, which has been discussed for a number of years, does not yet seem to be within the realms of early possibility. No outstanding developments have been made in protective wrappings and cable coverings, which are avoided if possible when cables have to be drawn into conduit. Advantages are to be gained from the liberal application of a suitable cable lubricant. Considerable increase in the life of Post Office cables subjected to chemical corrosion has resulted from the addition of a silicate inhibitor to the petroleum jelly used as a lubricant. Mitigation of severe conditions has been obtained in some cases by the planned insertion of insulating gaps of a simple type. Insulating gaps have not found favour abroad, where trouble arising from tramway leakage currents has frequently been countered by electrical-drainage connections to the tramway rails. The success that has been attained has in nearly every case been due to the formation of a local electrolysis committee and to their consideration of all the underground services—gas, water, electric light, telephones, etc., within the area. With this type of protection, in particular, segregated surveys have proved to be useless and individual remedies have been found to shift the danger to some other system and aggravate it. If electrical drainage is applied to one only of a number of systems buried below a street, elaborate precautions must be taken to ensure that the potential of the drained system is nowhere brought much below that of its environment. Controlled drainage meeting this requirement has been applied to telephone cables in Italy. In areas where the stray currents are large, consideration of the whole problem by a committee representing all interests is, however, regarded as likely to lead to the best engineering and most economic solution of the problem.

(9) ACKNOWLEDGMENTS

The authors wish to extend their thanks to Sir George Lee, O.B.E., the Engineer-in-Chief of the Post Office, for permission to read this paper.

BIBLIOGRAPHY

(1) S. C. Bartholomew: "Corrosion of Lead-covered Cables by Electrolytic Action," Institution of Post Office Electrical Engineers, Professional Paper No. 89, 1922.

(2) O. Haehnel: *Elektrische Nachrichten-Technik*, 1926, vol. 3, p. 99, and 1928, vol. 5, p. 171.

(3) "Leakage Currents from Electric Railways," U.S. Bureau of Standards, Technologic Paper No. 63, 1916.

(4) "Practical Applications of the Earth-current Meter," U.S. Bureau of Standards, Technologic Paper No. 351, 1927.

(5) C. and M. Schlumberger: *Annales des Postes, Télégraphes, et Téléphones*, 1932, vol. 21, p. 745.

(6) E. Soleri: "Protection of Underground Cables against Corrosion," Paris H.T. Conference, 1933, Paper No. 59.

(7) W. Beck: *Transactions of the Institution of Gas Engineers*, 1933, vol. 82, p. 917.

(8) R. Gibrat: *Revue Générale de l'Électricité*, 1934, vol. 35, pp. 203, 239.

(9) I. Panara: *l'Elettrotecnica*, 1934, vol. 21, p. 209, and 1935, vol. 22, p. 653.

(10) C. M. Longfield: *Journal I.E.E.*, 1935, vol. 76, p. 101.

(11) L. E. Vainicher: *l'Elettrotecnica*, 1936, vol. 23, p. 327.

(12) R. M. Burns: *Bell System Technical Journal*, 1936, vol. 15, p. 603.

(13) Comité Consultatif International Téléphonique, XI Assemblée Plénière, Copenhagen, 1936, Tome II bis, Partie II et III.

(14) L. J. Collet: *Annales des Postes, Télégraphes, et Téléphones*, 1937, vol. 26, pp. 1, 89.

(15) W. G. Radley: *Electrical Engineering*, 1938, vol. 57, p. 168.

(16) U. R. Evans: "Metallic Corrosion Passivity and Protection" (E. Arnold, London, 1937, reprinted 1938).

(17) J. W. Mellor: "A Comprehensive Treatise on Inorganic and Theoretical Chemistry," vol. 7, p. 672 (1930 edition).

(18) B. S. Cohen: "Research in the British Post Office," *Journal I.E.E.*, 1934, vol. 75, p. 143.

(19) A. Lacroix and A. de Schulten: *Bulletin de la Société française de Mines*, 1908, vol. 31, p. 79; A. Lacroix: *Comptes Rendus*, 1910, vol. 151, p. 276; A. Russell: *Mineralogical Magazine*, 1920, vol. 19, p. 64.

APPENDIX I

Compounds of Lead

A number of compounds of lead are mentioned in this paper, and a short summary is given below of their properties. This is mainly taken from vol. 7 of "A Comprehensive Treatise on Inorganic and Theoretical Chemistry," by J. W. Mellor.

Lead monoxide (litharge), PbO.

This is formed by direct oxidation of lead. Its colour is yellowish-white to reddish-brown, depending on the mode of preparation, and its specific gravity 9 to 9·5. It crystallizes in rhombic or tetragonal form, and dissolves in alkalis, giving plumbites.

Red oxide of lead (red lead), Pb_3O_4.

This is formed by heating litharge at a dull red heat in air. Its colour is scarlet or brownish-red, and its specific gravity 8·5 to 9·2. Chemically it often acts as though it were a mixture ($PbO_2 + 2\,PbO$).

Lead peroxide, PbO_2.

Lead peroxide is a product of the anodic corrosion of lead, or of a chemical oxidation of lead salts by agents such as hypochlorites, ozone, or hydrogen peroxide. It cannot be produced by heating lead monoxide or red lead. Its colour is reddish-brown to puce, it crystallizes in tetragonal form, and its specific gravity is 8·7 to 9·4. It will react with alkalis, giving plumbates, and is a powerful oxidizing agent.

Plumbates of the type $(Na_2O)_n\,(PbO_2)_m$ or $(CaO)_n\,(PbO_2)_m$.

These are usually prepared by warming lead oxides, alkali hydroxides, and oxidizing agents together, either dry or in solution. The properties have not all been determined satisfactorily. The substances tend to decompose into lead oxides, alkali hydroxides, and oxygen. Calcium plumbates have been described which are dark-coloured powders. These appear to be decomposed by acetic acid, giving lead peroxide and alkali acetates.

Lead chloride (cotunnite), $PbCl_2$.

This is a natural mineral, of specific gravity about 5·8, which crystallizes in white needles and plates. Its solubility in water at 15° C. is 0·9 g. per 100 g. of water.

Lead chlorocarbonate (phosgenite, or cromfordite), $PbCl_2 \cdot PbCO_3$.

This is a natural mineral. It can be made by boiling together lead-chloride solution and lead carbonate. It is composed of white, grey, or yellow, prismatic or tabular tetragonal crystals, and has a specific gravity of 6·0 to 6·9. Cold water decomposes the mineral, extracting lead chloride.

Lead carbonate (cerussite), $PbCO_3$.

This is a natural mineral. It can be prepared by the action of soluble carbonates on soluble lead salts. It is composed of white, tabular, prismatic, or rhombic crystals, has a specific gravity of about 6·5, and is almost insoluble in water.

Basic lead carbonate (white lead), $2PbCO_3 \cdot Pb(OH)_2$.

The composition of this substance is somewhat indefinite. It is made by the action of atmospheric moisture and carbon dioxide on lead in the presence of some catalyst such as acetic acid. A dense white non-crystalline powder, it has a specific gravity of 6·4 to 6·8.

Lead sulphate (anglesite), $PbSO_4$.

This is a natural mineral. It can be prepared by precipitation from a solution of a lead salt by a soluble sulphate. Composed of colourless rhombic crystals, it has a specific gravity of 6·1 to 6·4, and is an inert neutral substance almost insoluble in water.

DISCUSSION BEFORE A JOINT MEETING OF THE TRANSMISSION SECTION OF THE INSTITUTION OF ELECTRICAL ENGINEERS AND THE CHEMICAL ENGINEERING GROUP OF THE SOCIETY OF CHEMICAL INDUSTRY, 8TH MARCH, 1939

Mr. H. J. Allcock: It must be agreed that the problem of corrosion is of the greatest importance not only to telephone engineers but also to transmission engineers, and, as such, is of the greatest possible interest to the Transmission Section.

The method of examination outlined in Section (5) should be an essential feature of investigation into corroded lead sheaths, as it is mainly by a careful examination and a complete co-ordination of the observations and results of tests that it is possible to determine, and in many cases rectify, the causes of corrosion—whether they be electrolytic or chemical. This is well brought out in Section (5.4), where the importance of local conditions is stressed. The type of soil in which the cable is laid can have a very great effect on the probabilities of corrosion. For example, weathering can take place on a cable buried underground in very porous soil such as sand, whereas no weathering would take place in impervious soil such as clay. Alternate wet and dry conditions underground, more especially in a porous soil, would also prove deleterious.

The scope of the title is somewhat wider than the field actually covered by the paper, which deals mainly with questions of telephone cables drawn into ducts. There are, however, many miles of power cables in this country which, by the very fact that they are laid underground, are exposed to the possibilities of corrosion.

The mileage of plain lead-sheathed power cables drawn into ducts is relatively small, but certain troubles have been experienced with such cables, more especially in rural areas. Fortunately, the flexibility which, according to the authors, is essential for any underground telephone cable system, is not so necessary in the case of an underground power system, and although it is becoming more customary to lay spare ducts when laying main transmission feeders, the cables which are finally pulled into these ducts are almost invariably waterproof-served. Again, the problem of pulling one cable over another in

the same duct line rarely arises, except in certain cases of pilot cables which, once installed, are undisturbed except in cases of major reorganization or faults. Where the necessity does arise an effective means of reducing the friction—and therefore the chances of tearing the waterproof servings—may be provided by applying graphite to the cable, preferably at the factory during the final manufacturing operation.

The greater part of the power cables in this country are laid direct in the ground and have either been served with waterproof coatings or armoured and served, and this, except in the case of the very worst conditions, has resulted in a very small incidence of corrosion. In past years the question of protection of these power cables has exercised the minds of the cable makers, and a great deal of research work has been carried out with a view to improving the performance of these protective coverings. Several conclusions have been arrived at, the first of which is that in a protective covering containing both fabric and compound the most important part in the protection is played by the compound, the fabrics acting merely as separators to isolate the various layers from each other. It has been found that a given thickness of waterproof compound will provide much greater protection if it is divided into a number of isolated layers, and the function of the fabric materials is to isolate in this way. Secondly, the proper choice of the waterproof compound has been considered and in recent years there has become available a range of petroleum residues, some of which are air-blown, which have good chemical stability. There are also the natural asphalts, which again have good chemical stability and are somewhat more weather-resistant than the petroleum residues. Prior to the introduction of these materials the materials normally used were coal tar and coal-tar pitch in various proportions, or a natural asphalt thinned with coal tar. Unfortunately, coal tar and coal-tar pitch oxidize readily and craze and crack, so permitting access of moisture to the lead sheath, with consequent corrosion. The coal tar and coal-tar pitch products have therefore been rejected in favour of the more stable materials.

It has been found that the most satisfactory serving for an unarmoured cable, or bedding for an armoured cable, consists of two paper tapes, one cotton tape, and one hessian tape, applied in the order named; all being impregnated prior to application in stable waterproof compound of the types previously mentioned, with the waterproof compound applied over each layer during the serving operation. This provides a maximum possible number of layers of compound in the normal thickness of $\frac{1}{10}$ in. while still maintaining in the serving sufficiently good mechanical properties to resist abrasion during the process of laying the cable, or, in the case of an armoured cable, a good bed on which to apply the armour wires. In the case of armoured cable, the normal finish over the wires consists of two impregnated hessian tapes, with the appropriate waterproof compound.

In those cases where conditions are known to be exceptionally severe, from either a chemical or an electrolytic point of view, the protection outlined previously is insufficient. In the past, such cables have been laid solid in bitumen, but this has the effect of seriously reducing the current-carrying capacity, and the modern practice is to do away with solid laying and replace the normal servings by a rubber or rubber-wax or other similar compound coating applied overall.

Protection of power cables in stray-current fields by increasing the longitudinal resistance of the earth-current path by means of insulated joints has been carried out to some extent in America in connection with plain lead-covered cables drawn into ducts. The isolation of single lengths of power cable might, however, be dangerous, because under fault conditions, where there is a fault between a phase and earth, there may be a path of sufficiently high resistance back to the operating station to interfere seriously with the functioning of the protective devices. Again, in power cables the incidence of electrolytic corrosion is much lighter than that of chemical corrosion, being of the order of 1 to 4, and it is therefore much more important to guard against chemical rather than electrolytic corrosion. In this connection, it would be interesting to learn the relative incidences in telephone cables.

Mr. P. J. Ridd: The authors refer to the fact that little has been published in this country concerning the corrosion of underground cables, and so far as the Post Office is concerned the reason is not far to seek. The subject of electrolytic corrosion has been acutely controversial, and the presentation of much of the valuable information contained in this paper would not have been possible other than in the friendlier atmosphere recently created. Happily, on the initiative of the Engineer-in-Chief to the Post Office, and our Past-President, Sir George Lee, members of The Institution representative of traction and telecommunication interests have been brought together in consultation to consider means of minimizing electrolytic corrosion of underground cables. This co-operation will be beneficial from every point of view.

There is, I consider, good ground for the authors' anticipation that the extent of damage by corrosion may be reduced, and in fact a slight but promising reduction on the 1936 expenditure has recently been recorded.

The Post Office has obtained a considerable measure of protection against chemical corrosion by the use in chemical-corrosion areas of cables protected by bituminized hessian lappings; in fact, we have no record of the failure through chemical corrosion of a cable so protected. I go further than Mr. Allcock in saying that such cable is not suitable for use in an area in which electrolytic damage may be anticipated: in fact, such protection might render the position more acute.

Concerning the authors' map of the corrosion areas in the south-eastern part of England, we have been informed by many water undertakings in Kent of the effect of soils on their pipes. In some localities lead service pipes are immune, in others lead and galvanized-iron service pipes are subject to corrosion, and in yet others steel mains and even cast-iron mains are severely corroded. The evidence collected by the water companies on the usefulness of hessian coverings has been generally similar to that of the Post Office, although in one or two cases failures have been reported even when the pipes have been protected with hessian coverings.

The authors state that less corrosion has been experienced in Germany than in other countries, and they

attribute this to the fact that German regulations are more rigorous; but the German regulation shown in Table 6 is not more rigorous than our Ministry of Transport regulation. A more probable explanation is that in Germany the regulation is more rigorously enforced.

The earthenware self-aligning duct has been used by the Post Office for 30 years. We have also tried in this country the type of concrete duct line cast in situ which is mentioned in the paper as being in use in France, but our experiments were not a success.

We try to keep our duct lines reasonably dry, because in the event of a breakdown, when we have to get at the cables in a hurry, we would rather not have to spend time in emptying water from manholes and ducts. Apart from this, and excluding areas where the soil water is dangerous, I am not sure that I would not just as soon have my cables under water and know when they go wrong one by one, as have them kept dry and risk more failures when a flood occurs.

I wish to emphasize that the reduction in sheath current shown by Fig. 18 was obtained by methods that are more in the nature of research than practical engineering work. It is clear, of course, that if we inserted sufficient insulating gaps we could prevent any current from getting on to the sheath, and the more that we depart from that condition the more sheath current we may expect to get. If we put our insulating gaps at too great a distance apart we may, by driving the current off the sheath where the gaps occur, cause greater trouble than would exist if they were not inserted.

Prof. H. E. Watson: It is perhaps not always realized that lead absorbs oxygen exceedingly rapidly, very much in the same way as does aluminium. Chemical corrosion may be regarded as the direct oxidation of lead by oxygen and the solution of the oxide by some agent such as an organic acid. Such corrosion is nearly always a uniform process and, unless it is vigorous, it is often not very damaging, especially as it is a fortunate provision of nature that, when there is a tendency to chemical corrosion, some inhibitant—for example, a sulphate—is frequently present.

The next kind of attack is also produced by oxygen, but in combination with an electric current. The authors describe this also as chemical corrosion, but I think that it would be as well to distinguish it from the type I have already mentioned. Where there is any inequality of the lead, electrolytic action tends to take place locally, leading to "differential oxidation," and the result is a pit where the quantity of oxygen is least. This is usually at the points of contact of the cable with other bodies, particularly if a little moisture is present.

Both chemical and internal electrolytic corrosion may be accelerated by strain. We all know how readily a rubber tube oxidizes and cracks where it is stretched; exactly the same thing happens in the case of lead, the corrosion frequently being of the intergranular type. I have seen even armoured and braided cables taken from a dry mine shaft, where they had been hanging freely in air, completely corroded between the grains.

Another important factor is the grain size of the lead. This is usually recognized by cable manufacturers, the normal practice being, as soon as the cable is extruded, to quench it and then give it a small bend. Unless this is done, or if the cable is bent when it is hot, abnormal grain growth may occur, leading very often to bad intergranular corrosion, especially where vibration is present. This aspect of the subject has been dealt with recently by Mr. Brinley Jones.*

The references in Table 3 to corrosion in longitudinal marks or lines suggest at once a scratch in the cable, which produces a strain sufficient to induce corrosion. This suggestion is supported by the authors' remarks on lubrication, because lubricated cables are obviously less strained than unlubricated ones when they are being put into the conduits. It would be interesting to know whether longitudinal corrosion is less in a lubricated cable than in an unlubricated one.

I notice that no attempt has been made by the authors to estimate the organic acids in corrosive solutions. These are usually more important than all the other factors which are determined, except perhaps the chlorides, which tend to break down protective films.

One way of preventing corrosion is to keep out oxygen, and this could be done in some situations by filling the conduits with water containing traces of carbonates, silicates, or sulphates, instead of trying to keep them drained. It is the half-and-half state which is so dangerous, as in the case instanced of the water in a conduit which dripped owing to cooling by ice.

Turning to the question of alloy sheathings, the authors say that no one alloy is superior to pure lead under all conditions of exposure. Does not this depend on how the corrosion is measured? Does one alloy dissolve uniformly and another give intergranular corrosion? I notice that tellurium-lead is put low down in the order of corrosion resistance given on page 697, despite the fact that it has a very fine grain structure and is less susceptible to thermal creep than pure lead. It would be interesting to know the exact factors taken into account by the authors. The recently developed copper-tellurium-lead is not mentioned.

In the case of electrolytic corrosion from an outside source, would it be of assistance to connect the cable at suitable places to an iron or zinc "earth"?

Mr. P. B. Frost: I wish to add a few remarks to the information given by the authors on the subject of drainage, and particularly the controlled electrical drainage which has been adopted at Milan and some other cities in Italy.

The whole telephone cable network of Milan was broken up into 16 entirely separate sections, by means of about 350 insulating gaps, and each of these sections had to be cut up into about 20 smaller sections by means of further insulating gaps, each bridged by an adjustable resistance. At each of the 16 points of drainage it was necessary to provide a resistance to adjust the potential of the cable to that of its environment at that particular point, a fuse to protect the sheath against currents heavy enough to damage it, a rectifier to prevent reversal of current, and an earth plate to give a connection to the earth at that point. In addition, a pair of pilot leads had to be run back to the central controlling point (in this case, the telephone exchange) from each of the drainage points.

Measurements of the p.d. between cable and earth are made twice a day on every pair of these pilot leads,

* *Journal of the Society of Chemical Industry*, 1938, vol. 57, p. 251.

except those to which recording voltmeters are permanently connected. During certain periods some of the pilots have to be connected to an automatic alarm circuit which operates if the voltage between cable and earth exceeds $+ 0 \cdot 5$ volt or $- 2 \cdot 0$ volts.

An efficient drainage device should pass current in the correct direction at as low a voltage as possible; it must prevent a reversal of current; and it should progressively lower the resistance connected between the cable and rail as the current tends to increase. These requirements are not fully met by a rectifier, because even a single-element rectifier needs about 1/6 volt to cause any current to flow in the forward direction, and such a rectifier will only withstand a voltage of 4 in the reverse direction. On tramways and electrified railways considerable reversals of voltage occur under some conditions, and it is difficult to find a device which will give a low enough conductance in the forward direction and at the same time sufficient resistance to a reversal of voltage.

In some other countries use has been made not only of rectifiers but of polarized relays and ballast resistances in combination with some form of contactor. In America, under certain conditions, recourse has been had to contactors operated by local batteries.

All this apparatus is costly to install, supervise, and maintain; and we are probably all in agreement that such a burden should not be thrown upon a telephone administration, which suffers damage from the effect of stray currents without contributing to them. But for the fact that the tramway systems in Italy are working under very severe conditions and that there are no regulations to govern their operation, the telephone authorities would never have faced the heavy expense and inconvenience associated with electrical drainage.

Mr. Allcock pointed out that an insulating gap in a power cable is inadmissible because of the need for maintaining a return path for fault current. In carrier telephone cables we have found that where gaps are inserted there is a definite increase in cross-talk between the circuits in the cable. This drawback may be overcome by shunting the gap by a condenser, a further complication.

It is rather significant that in the countries that have used drainage—Belgium, the United States, Japan, and Italy—there appear to be no regulations which govern the working of tramways.

The authors state on page 703 that "The replacement of tramways by trolleybus systems will, where the return conductor is insulated, result in a material improvement in the electrolysis hazard." That is a very moderate statement. I would go so far as to say that where the trolleybus system is all-insulated, as in London, the electrolysis trouble will completely disappear; except, of course, for actual faults on the system, which are quickly located and removed.

In the Post Office we have recently standardized the use of sodium-silicate petroleum jelly emulsion for the purpose of lubrication, when drawing-in cables. We have developed a grease pump for ensuring a sufficient and complete covering of jelly over the cable. Unfortunately, the process of drawing-in very often scrapes off this lubrication in places, and no doubt does leave such lines and scars as those to which Prof. Watson referred. The silicate jelly will not quickly gain access to those scratches once the cable is in place unless there is a fair circulation of duct water.

In the case of power cables, which the authors refer to as having gained much benefit from a thick grease lubrication, I assume that although scars or scratches doubtless occur, the warmth of the cable soon ensures a redistribution of the grease over the scratched parts of the sheath.

With regard to the use of a protective covering in a duct, we have found that hessian-covered cable cannot satisfactorily be withdrawn after a few years—and we very often have to withdraw cables—because the hessian rots, becomes detached, and blocks the duct. In regard to alternative satisfactory materials, the cost of a covering of rubber-wax mixture is high. In addition, the protective covering frequently leads to a considerable loss of duct space. As an extreme example, we sometimes have cases in which two cables, unprotected, could be drawn into the same duct, but when both are protected, a separate duct is required for each.

Mr. S. Beckinsale: With regard to the question of cables in ducts, I should like to point out that the ducts act as land drains in many cases. Some of the trouble which has been experienced in Kent and other agricultural districts is due to the fact that artificial manures and humic acids from ordinary manures get into the ducts and cause corrosion of the cables. I hope that the practice of laying power cables in ducts will be abandoned, as it gives rise to more trouble than is experienced when the cables are buried direct in the ground. Unlike telephone cables, power cables are subjected to alternations of temperature arising from loading cycles and these have an important bearing on power-cable corrosion.

When power cables are buried direct in the ground the soil has to be carefully examined. We have found that if a cable is buried in clean, good clay there is little trouble, but cables buried in a porous type of soil often need special protection, as Mr. Allcock has indicated.

In those areas where the ground is heavily manured we have come across two types of corrosion. In one, the corrosion products contain a high percentage of nitrate; the action is purely chemical and not associated with stray currents. It not only very often destroys the cable, but also so oxidizes the protective servings that they are completely useless. The second type of corrosion noticed in these highly manured areas is the chloride type. Where there is serious sewage contamination, the corrosion product usually has a high chloride content, and this is not due to electrolysis.

Referring to the use of lead alloys for cable sheathing, when corrosion conditions are sufficiently severe there is little to choose between pure lead and the alloys. Pure lead is, however, very prone to intercrystalline corrosion, largely because of its large grain size; but it is more resistant to creep than its alloys. A cable-sheathing material should have resistance to corrosion, resistance to creep, and (sometimes) fatigue resistance. I recommend a medium-sized crystal in lead as giving a very satisfactory life under ordinary conditions of service. Lead-tellurium creeps rather badly, although having good fatigue resistance.

Power cables are expected to last for many years, and it is not considered that the increase in life given by such

inhibitors as sodium silicate would be sufficient. We have found that inhibitors increase the life of the cable sheath, but to obtain real protection it is necessary to apply some form of coating. Rubber wax has been very satisfactory for this purpose on telephone cables, but it might not be suitable for power cables owing to the high temperatures and alternations of temperature which are met with.

In porous soils I do not think it is so much a question of the waterproofness as of the gastightness of the protection applied to cables. In power cables we often come across isolated spots of corrosion, and I consider that these indicate positions where vapours from the soil have gained access to the cable sheath. These vapours probably consist of water, oxygen, carbon dioxide, and acetic acid (produced by the breakdown of organic matter in the soil or in the cable-wrappings). One of the possible ways of preventing such corrosion is to provide a uniform bituminous coating for the lead sheath. Such a coating will stay in position during the life of the cable, whereas those made from the early coal-tar products tended to flow to the under-side when the cable reached a high temperature, leaving the top side unprotected. This was a great drawback, as it is at the top side of the cable that corrosion often occurs. A very thin coating of suitable bituminous material will prevent chemical attack; electrolytic corrosion, on the other hand, is more difficult to deal with. Nevertheless, bituminous materials have quite good breakdown values: a typical value is 35 kV, using a 0·05-in. gap between $\frac{1}{2}$-in. spheres. Bitumen having such a breakdown value would stand up to all except the most severe conditions of electrolytic corrosion.

Builders have long used bituminous coatings to prevent the deposition of moisture from the atmosphere on cement, and I think that bituminous coatings on lead-sheath function in the same way.

Mr. M. B. Donald: The authors showed on the screen a map of S.E. England divided according to Post Office areas, and it would be interesting from the corrosion point of view to superimpose on it a geological map of the area. There are difficulties in connection with the waters in Kent, especially with regard to sodium carbonate. Special precautions have to be taken with aluminium drinking vessels in certain parts of Kent, because they corrode very easily on this account.

Dealing with the question relating to tellurium lead raised by Prof. Watson, the usual creep test for this material is the same as the test for creep in iron, namely to keep it at a certain temperature under a certain load and then measure the elongation. This standard procedure shows that tellurium lead creeps more than plain lead, but under practical conditions, e.g. in the lead chambers of sulphuric-acid works, tellurium lead stands up just as well as, or even better than, pure lead.

The authors state that the practice of providing insulation between the various portions of the cable is not universally favoured; would they elaborate that point?

Some time ago, it was found that chlorinated rubber gave an extremely hard tough coating for the outside of steel pipes which resisted all abrasion. Have the authors tried chlorinated rubber for the outside of lead cable, and, if so, did they find it satisfactory?

Mr. S. C. Bartholomew: The type of octagonal duct used by the Post Office is quite watertight, but was costly to lay. Lead cables in the concrete ducts which the Post Office took over from the National Telephone Co. in 1912 gave trouble in a few cases, and we suspected that this corrosion might be due to the concrete itself. Here I should like to point out that there seems to be no mention in the paper of the effects of concrete upon lead, although the French and German engineers take the precaution of inserting either tar or bitumen compound where lead comes into contact with concrete ducts. The French have a machine for putting tar or bitumen into the concrete ducts, which are formed in long lengths in situ.

I am sorry to hear that the peroxide-of-lead test for electrolytic action has been put in the background and a chloride test substituted. It was an old friend, very useful in a dispute. Dr. Haehnel, who first suggested the chloride test as superior, has apparently been proved to be correct in his views regarding it.

I believe that one of the first ternary lead alloys (lead-tin-antimony) was employed by the Post Office for making the pneumatic tubes for conveying telegrams between the Central Telegraph Office and various Post Offices in the City of London and the West End. Some of these tubes have been in use over 60 years, and I cannot remember a single case of corrosion, either electrolytic or chemical. The tubes were, however, protected by iron pipes which were very carefully laid.

I was told that in America the electrolysis problem had been solved by properly controlled drainage systems, but that the cost of this method of dealing with electrolysis was about £200 000 per annum. This was many years ago, when street tramways were common, and no doubt conditions are different now.

Dr. Radley may remember that some years ago in Paris at a Commission Mixte Internationale Conference on Electrolytic Corrosion Prof. Chappuis, consultant to the gas interests, contended that where there is electrolytic action on a pipe caused by leakage currents from a tramway rail or electric railway it gradually becomes worse, because the metal taken from the pipe by the leakage current more or less fills up the soil between the rail and the pipe with metal, thus forming a low-resistance conductive path, and so increases the current causing the electrolytic action. He showed that action in process by means of X-rays and a small battery cell, but subsequent experiments made at Dollis Hill on a much larger scale failed to show that the effects were appreciable. I should like to know whether there have been any developments in this matter, as Prof. Chappuis was very emphatic as to its importance.

I think that d.c. railways with a third rail and uninsulated return will present a much more serious corrosion problem as time goes on. According to the Acts of Parliament, the Ministry of Transport is supposed to make regulations, so that electrolytic action by stray currents is prevented both in the case of electric tramways and in the case of railways. There are regulations in the former case which are obviously not completely effective, and in the case of electric railways there are regulations for those run underground in metal-lined tubes but none, I believe, for those above ground.

The London Underground Railways employ an insulated return, whilst the others use the ordinary uninsulated rails for that purpose, and one would think that regulations are more necessary in these cases. Suggested regulations for this latter type of railway were drawn up some years ago by a committee appointed by the Ministry of Transport. They (the suggested Regulations) were of a very general character, and did not deal with the all-important question of allowable voltage-drop on the uninsulated return rails.

Mr. K. S. Wyatt: It is important to remember that all the telephone cables dealt with by the authors have been under the supervision and control of one body, the British Post Office, whereas power cables are operated by a large number of supply authorities, and for this reason troubles on power cables due to corrosion are perhaps not always recognized as such. This is because the supply engineer is primarily interested in "continuity of service." When trouble occurs on a line the faulty portion is removed and a new piece of cable put in immediately; consequently, diagnosis of the fault is often omitted.

One of the ways of remedying corrosion troubles is to form a corrosion committee of the services which are affected. It was my good fortune to watch the operation of such a committee formed by the various public services in an American city. Within 2 years the cost of corrosion troubles dropped to approximately one-third of its former high value. I believe that similar experience is universal in American cities.

Recently we had an unfortunate experience with a $2\frac{1}{2}$-mile length of steel pipe in which a pressure cable was installed. Widespread corrosion was found, which was partly chemical and partly electrolytic. The authors' experience was confirmed by our studies of this line: electrolysis was evidenced by deep isolated pits, which were undercut; chemical corrosion was evidenced by general shallow pitting, and the corrosion products were often of a powdery nature. We found that the most valuable method of determining the cause of the trouble was to make continuous measurements of the voltage drop in the pipe from point to point along the length of the route, and then to plot a curve showing the flow of current along the route. A close examination of this curve enabled the localities to be determined where the current was either leaving or entering the pipe. In this way we could readily track the source of the trouble.

The successful solution of this problem of electrolytic corrosion from stray currents resulted from co-operation with the tramway authorities. Immediately this problem was brought to their attention, a series of tests were made which consisted of shutting down various substations one after the other over a large area. The trouble was finally located at an earth switch some 3 miles away from the line, for when this switch was opened the current flowing in the pipe immediately dropped to zero.

It seems to me that the methods mentioned by the authors—insulating sleeves, bonding, and electrical drainage—are only palliatives, and costly ones too, because they have to be watched constantly and require a great deal of upkeep. It is far better to trace the source of the stray current and to eliminate it.

It is an open question whether electrolysis due to stray current can be prevented by any type of coating so far tested. The coatings used in the past have been made of fibrous material, and any fibre, however deeply embedded in bitumen, will convey moisture from the surface of the serving to the metal of the cable sheath. The only way in which to overcome this difficulty is to interpose one or two membranes which are impermeable to water. These membranes must be flexible, to allow for movement of the cable due to temperature-changes and ground movements.

There are several types of coating which have recently been developed to meet these requirements. They generally consist of a rubber membrane reinforced with bitumen and fibrous tapes.

I frequently come across the statement that pure lead creeps less than any of the alloy leads, but a recent report from the University of Illinois, containing a very comprehensive study of lead creep, indicates that quite the reverse of that statement is true. Calcium lead has a lower creep rate than pure lead.

Mr. E. F. H. Gould: An important conclusion which can be drawn from this paper is that it is now possible by means of chemical and microscopic examinations, together with electrical tests in the field, to determine in the majority of cases whether the cause of the corrosion is electrolytic or chemical, and that in cases of electrolytic damage a distinction can be made between corrosion arising from self-generated currents and that arising from currents originated from external sources of electricity in the vicinity.

Referring now to the test mentioned in Table 2 where a large excess of current leaves the electrode and produces the corrosion, the result could be expressed by saying that the amount of corrosion is proportional to the algebraic average of the current. I suggest that it is possible that one could go further and conclude that the resulting corrosion is for all practical purposes directly proportional to the algebraic average of the potential producing that current, and in particular that the corrosion arising from two tramway systems which are similarly constructed could be compared by the algebraic average of the potential difference between corresponding points on the two systems.

As will be seen from Table 6, the regulations governing the potential difference between points in the tramway track are the same in Australia as in this country, but earlier in the papers the authors stated that the resulting corrosion is very much worse there than it is here. It may be, as was implied earlier in the discussion, that the regulations are not so strictly adhered to, but I suggest that it is possibly attributable to the fact that the method of construction of the tramways in that country differs from that which is adopted here. On the other hand, the corrosion damage in Germany is negligible, and tests which we have carried out in Great Britain would suggest that the limits imposed in that country are no more severe than those which apply here. It is important, in fact, to bear in mind that the mere limitation of potential difference is no safeguard. It must be taken in conjunction with a high standard of track construction.

Dealing with methods of protection against stray currents, it is suggested by the authors that the protective covering could be confined to the area where the cables

pick up the current. Alterations in the method of operating a tramway system may, however, change what is a pick-up area at one time of the day to a discharge area at other times, and as a consequence measures for mitigating corrosion damage have to be applied to the whole network. Estimates show that in many large towns in this country several thousands of insulating gaps would be necessary, if the whole of the telephone network were treated on the same basis as that adopted by the authors for their experiments on insulating gaps. Apart from the large expenditure of money which this would involve, another objection to such a scheme is that the continuity of the sheath would be interrupted to such an extent by the presence of so many insulating gaps, that the normal benefits of the screening effect would be lost, and in some types of cable the transmission efficiency would be impaired.

Mr. L. H. Daniel: It would seem advantageous in some cases to use armoured cables, not only from the point of view of the increased protection against corrosion which could be achieved, but also because the damage sometimes experienced due to creepage with traffic vibration could be overcome, particularly in the case of trunk cables, to which it is not necessary to have access at very frequent intervals.

In Section (4.21) the authors refer to the effect of environment in the case of cathodic corrosion, and it would be interesting to know to what particular environments they refer. In Section (4.22) the statement is made that corrosion due to alternating current can be assessed as amounting to 1 % of that due to direct current. It would be of interest to know whether this can be taken as applying to practical cases, or whether it is based upon laboratory experiments. In this connection I should like to mention an aspect of a.c. corrosion which is apparently not considered important by the authors, namely the effect of earthing a.c. supply systems. This aspect of corrosion has become important recently in connection with damage to water mains, and is being investigated by the Electrical Research Association. It seems, from some experiments which require confirmation, that a.c. corrosion may amount to more than 1 % of the corresponding d.c. corrosion in some instances.

It would be of interest to those who are involved in the more practical aspect of the problem, to know whether the methods of microscopic examination and the chemical tests which are outlined in the paper, and which have proved valuable in the case of lead, could be applied to other common metals. For example, could they be applied in the case of cast-iron and steel pipes?

The authors state that the Schlumberger method is not applicable to the measurement of cables laid in ducts. One can go further and say that it would be very difficult to apply it, on a quantitative basis at least, to cables laid directly in the ground, because frequently one has to deal with a reinforced-concrete road and the presence of other pipes in the vicinity. It seems to have some advantage, however, from the point of view of qualitative examination.

The authors state that the movement of the loop galvanometer is aperiodic. It would be of service to know what is the response of this instrument to alternating current, and whether the application of thermionic-valve circuits might not be usefully considered. With such circuits one could readily discriminate between alternating and direct current, and the sensitivity of the apparatus would not be seriously limited.

Mr. A. O. Gibbon: May I inquire whether the authors have had any reports concerning corrosion on lead-covered cables carried in octagonal ducts. These stoneware ducts are used by the British Post Office on congested telephone routes and, as the ducts are surrounded by several inches of concrete, there have not been many breakdowns due to corrosion.

Corrosion difficulties have been reported in buildings where power, lighting, and telephone cables are laid under the plastic cement floors. Perhaps the authors will say whether this matter has been investigated by the Engineering Department of the Post Office and by other authorities.

Dr. W. G. Radley and **Mr. C. E. Richards** (*in reply*): The suggestion has been made that the title indicates a somewhat wider field than that actually covered by the paper, since the latter is confined mainly to the problems associated with cables pulled into ducts. Our experience has been principally in connection with such cables; but, as pointed out by several speakers, they are more liable to corrosion than cables laid underground in other ways. It is extremely difficult to give other than very approximate figures for the relative incidences of electrolytic and chemical corrosion of cables pulled into ducts. Since both types of attack are associated with circulating electric currents there must necessarily be some overlapping in any system of differentiation. Leakage currents from external sources, such as traction circuits, are, however, definitely suspected as the cause of roughly 50 % of the corrosion failures of telephone cables in this country. We do not completely share Mr. Bartholomew's fears as to the effect of d.c. electrified railways, as, in our experience, such railways have been less troublesome than tramways. A partial explanation may be found in the much higher insulation of the running rails in the case of the railway.

In reply to Mr. Daniel, corrosion may occur in an area where lead is cathodic to its surroundings if the composition of the soil or water is such that large concentrations of alkali result from passage of the current. The statement that corrosion due to alternating currents is 1 % of that due to direct currents is a popular assessment. It can probably be traced to Hayden,* although Halperin and Miller† consider the figure to be less. Our own experiments confirm that this is the order of the magnitude, but considerable variations are found with local conditions. In the endeavour to investigate the incidence of corrosion without external stimulation a geological map has been superimposed on one showing the distribution of corrosion in South-East England, as suggested by Mr. Donald. The correlation was poor, although there was a slightly increased tendency for cables to corrode just after they had entered a clay soil. Mr. Allcock referred to the effect of the type of soil on the liability to corrosion of buried pipes. Various attempts have been made, especially in America, to classify soil types according to their liability to cause corrosion, also to co-ordinate

* J. L. R. Hayden: *Transactions of the American I.E.E.*, 1907, vol. 26, p. 201.
† H. Halperin and K. W. Miller: *ibid.*, 1929, vol. 48, p. 24.

this liability with measurements of such properties as electrical resistivity and pH value. Although such correlation is possible, the anomalies encountered in practice are so numerous that generalizations have but a limited practical value. Prof. Watson raised the question of the effect of strain. The acceleration of corrosion by stress of the metal is well known, but it is not expected to affect underground cables, and a few experiments which we conducted with strained and unstrained lead did not give any conclusive results.

In connection with the construction of duct lines, there is, as is suggested by Mr. Beckinsale, a danger of such lines acting as land drains. The disadvantages of a duct that is partially wet and within which cables are tending to discharge current are fully appreciated. On the other hand, it is no more easy to keep a duct full of water than it is to keep it dry, and in areas where there is a tendency for the cables to collect current considerable advantage is gained by keeping the ducts as dry as possible. This will increase the resistance between the cables and the ground, and so decrease the total amount of current carried by the cables. The octagonal ducts used by the Post Office are generally watertight, but cannot always be made absolutely so. Corrosion of cables in such ducts does occasionally occur. The monolithic duct lines known to us have failed to hold water when tested.

In reply to Prof. Watson, except in areas where there is a known tendency for cables to collect current the sheaths are normally connected to an earth plate where they enter manholes, and in some cases zinc earth-plates are used. The protection afforded by a zinc earth-plate is, however, only effective over a short distance and the plates require frequent renewal.

Because somewhat elaborate methods of investigation have been described in the paper, it must not be thought that the immediate restoration of telephone service after a failure is not as important as the question of "continuity of service" to a supply engineer. Field tests take place after the service has been restored, or are designed to locate areas where electrolysis may be expected. The chemical tests in the laboratory are undertaken after the damaged cable has been replaced. It is possible that the laboratory examination of corroded iron and steel pipes might be conducted on the same general principles, but the details of the examination would differ. In connection with the remarks by Mr. Beckinsale and Prof. Watson, the presence of nitrites in lead corrosion products can often be associated with manured ground, but we are doubtful whether a high chloride content can be attributed to the action of manure alone. Organic acids arising from jute wrappings have in some cases given rise to corrosion which has perforated cable sheaths. Such acids are tested for in many cases, although they were not quoted in the paper. Generally speaking, corrosion due to organic acids is more prevalent in "nominally dry" situations than in wet ones.

Mr. Bartholomew recalls the experiments carried out by Prof. Chappuis, who observed the growth of a "tree" of metallic lead between electrodes buried in sawdust impregnated with lead nitrate. As the tree grew, so the resistance between the electrodes decreased and the leakage current increased. We were, however, unable to reproduce the phenomenon when the electrodes were buried in damp earth and at a separation corresponding to that between a tramway rail and a cable.

We are in agreement with the statement made by Mr. Daniel that the Schlumberger method is difficult to apply where reinforced-concrete roads intervene. The method has found its greatest field of application in the measurement of the current interchange between oil pipe-lines and the ground in America, where the pipes are buried in open country. The loop galvanometer is suitable for alternating currents up to about 5 cycles per sec. Thermionic-valve circuits cannot readily be employed, as the potential to be measured is largely d.c. and may be less than 1 millivolt when the instrument is being used in shunt across a length of cable sheath.

Mr. Beckinsale, Prof. Watson, and Mr. Wyatt raised points in connection with the choice of sheathing material. Taking all the factors into consideration, lead with medium-sized crystal grains probably forms the best material for the sheaths of underground cables. Some reports from the University of Illinois have indicated that lead creeps faster than the alloys, but it is now agreed* that at low stresses lead is less liable to creep than the alloys. Lead-tellurium not only creeps very badly but also work-hardens so readily that it would be difficult to handle in awkward manholes. We have no reliable information regarding lead-calcium alloys. With respect to the corrosion resistance of the various alloys, the order of merit given in the paper relates to the conditions peculiar to their use as cable sheathing materials, and may have no bearing on their use for any other purpose.

At present the same types of waterproofing compound are used for the wrappings of telephone and power cables. Coal-tar products are not used as, in addition to cracking trouble, they are suspected of giving rise to corrosion of the lead. There appears to be no way in which a hessian or other fibrous wrapping can be made quite waterproof. A rubber-wax coating is effectively waterproof, but it seems doubtful whether this is a suitable material to put on power cables as it softens at a relatively low temperature. Chlorinated rubber coatings are well known as a means of protecting steel, but will not adhere well to lead. The pulling-in of one protected cable over another can be facilitated by the application of a graphite coating in the factory, but it is unlikely that such treatment would aid the withdrawal of the cable in some years' time.

The use of silicated petroleum jelly for lubricating bare lead-sheathed cables as they are pulled-in has the advantage that the silicate dissolves slowly in any water that is present and is thus carried to those parts of the sheath from which the lubricant has been removed by scraping. Lives considerably longer than those quoted in the paper are expected from silicate-treated cables, as the majority of the cables listed in Table 5 had not failed when the count was made. All Post Office cables are lubricated as they are pulled in.

Several speakers referred to protection by the use of insulating gaps. The difficulties which have to be overcome in this connection are numerous. A localized discharge of current on one side of the gap may be prevented by the use of pipe or sheath wrappings. The effects of insulating gaps in preventing the flow of sheath current

* H. F. Moore, B. B. Betty, and C. W. Dollins: *Bulletin, University of Illinois*, 1938, vol. 35, no. 102, p. 33.

in a power cable under fault conditions and in reducing the efficiency of the sheath of a telephone as a screen against noise interference* have also to be considered. In addition, their effective use as a means of preventing electrolysis demands much pre-measurement in the field.

We thank Mr. Frost for the additional details which he has given of the elaborate system of controlled drainage in use in Milan, and Mr. Bartholomew for his remarks relating to the protection of telephone cables by electrical drainage in America. In many American cities where street railway systems have been shut down the protection originally given by electrical drainage has been maintained by the connection of a small negative e.m.f. between the cable network and a suitable low-resistance earth-electrode system, such as the disused rails.

A number of speakers referred to the regulations in force in various countries. It must be admitted that the incidence of underground corrosion varies considerably. For many of the existing anomalies we do not know the explanation, which can only be found by careful examination of all contributory factors. These include not only the national regulations and their interpretation, but also standards of construction and maintenance, and geological conditions.

* W. G. Radley: *Journal I.E.E.*, 1934, vol. 74, p. 216.

A MEANS OF PROVIDING CONTROLLED ACCELERATION AND DECELERATION AND ALSO CONTROLLED REGENERATIVE EMERGENCY BRAKING ON WARD-LEONARD MINE HOISTS*

By H. FREEMAN, Associate Member.†

(*Paper first received* 12*th July*, 1938, *and in revised form* 1*st February*, 1939.)

SUMMARY

The paper is a brief description of a system devised by the author to exercise control over the rate of acceleration and deceleration of Ward–Leonard and Ward–Leonard Ilgner mine winders by purely electrical means, irrespective of the position of the driver's control lever. It also describes how the system is used for controlled regenerative braking in emergency. The paper consists of the following parts:—

(1) A description of the control exciter, with the method of field mixing used to provide the required output characteristic.
(2) A description of the field control resistance used to vary the characteristic according to the position of the cages in the shaft.
(3) The application of the control exciter in normal service.
(4) The application of the control exciter in emergency conditions.
(5) Results obtained.

INTRODUCTION

A great deal of attention has been paid during recent years to improved methods of braking during emergency conditions on large mine winders. This has been necessitated by the increasing depths for which winders are now being designed. In these cases a fairly accurate knowledge of the stresses on the rope is necessary in order that the dimensions of the rope may be kept down to reasonable figures compatible with an adequate dynamic safety factor. The shortcomings of the usual oil- or air-damped mechanical brakes are well known. The varying time between the emergency trip and the application of braking, and the uncertainty of the braking effort, are not conducive to ideal braking conditions. Therefore a satisfactory method of providing smooth controlled regenerative braking which would obviate the above shortcomings would be a distinct advance.

Furthermore, excessive stresses may be applied to the rope by the driver injudiciously moving his control too far either when accelerating or decelerating outside the range of the ordinary accelerating and decelerating cams. There are various mechanical devices which trip the hoist when this occurs, but their use is confined more to the purpose of preventing the continuation of excessive currents and rope stresses rather than to limiting the current demand or the rope stress. Any device, therefore, which would prevent ill-effects when the control lever was injudiciously moved would not only enable the maximum rope stresses to be more accurately predicted but would also make the hoist more "foolproof." The various devices which have so far been produced for braking the hoist, whether by mechanical or electrical means, have usually been arranged to bring the winder to rest in a given time, irrespective of loads in the cages or whether these are in the upcoming or downgoing cage. It is desirable in emergency conditions to bring the winder to rest as quickly as possible consistent with safety to men riding in the cages and to avoid overstress in the rope. With the constant-time method, if the time is set at a minimum consistent with safety to men it is likely that the rope will be severely stressed should an emergency trip occur near the bottom of the shaft with a fully loaded downgoing cage. In addition, with regenerative braking in the latter case the winder motor may not be of sufficient capacity to provide the necessary retarding torque. Or, if the time be set to a value which brings the stress or retarding torque in such a trip to reasonable proportions, then the winder is not being brought to rest as quickly as it might safely be if the downgoing cage were empty. The question of time, of course, is not so important in the case of the upcoming rope, as the stress on this rope is relieved during deceleration. Some means of varying the time of deceleration within certain limits according to the direction or magnitude of the cage loads would therefore be advantageous.

Three methods of controlling the generator field current are available. (*a*) By arranging that the field current is at a certain value when the winder has travelled a given distance during retardation. This is the method used for normal retardation at the end of the wind by means of the deceleration cams. (*b*) By arranging that the field current is at a certain value after the expiration of a given time during retardation. This method is used in a number of existing control devices, but does not lend itself satisfactorily to the varying-time method of control. (*c*) By arranging that the field current is at a certain value at a given speed of the winder during deceleration. This is the method used in the author's control system.

The author now proposes to describe a system which he has devised and fitted with successful results to the Gifford's Shaft winder at Champion Reef Gold Mines, which is of 1 150 h.p. (r.m.s.).

(1) THE CONTROL EXCITER

In the author's system an exciter is so coupled to the winder that its speed is proportional to that of the drum shaft. The exciter armature is permanently connected

* The Papers Committee invite written communications, for consideration with a view to publication, on papers published in the *Journal* without being read at a meeting. Communications (except those from abroad) should reach the Secretary of The Institution not later than one month after publication of the paper to which they relate.

† Kolar Gold Field Electricity Department.

across the generator field so that on the occurrence of an emergency trip it may supply the generator field with exciting current, the supply from the main exciter being cut off in these circumstances. The simple circuit dia-

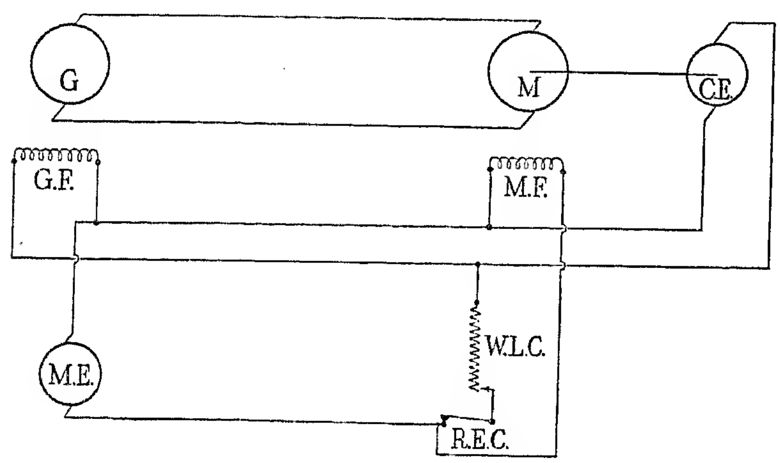


Fig. 1

gram is shown in Fig. 1, where G and M represent the main generator and motor respectively, G.F. the generator field, M.F. the motor field, C.E. the control exciter, M.E. the main exciter, W.L.C. the Ward–Leonard controller, and R.E.C. the emergency contactor. Fig. 2 shows the generator field current plotted against control exciter

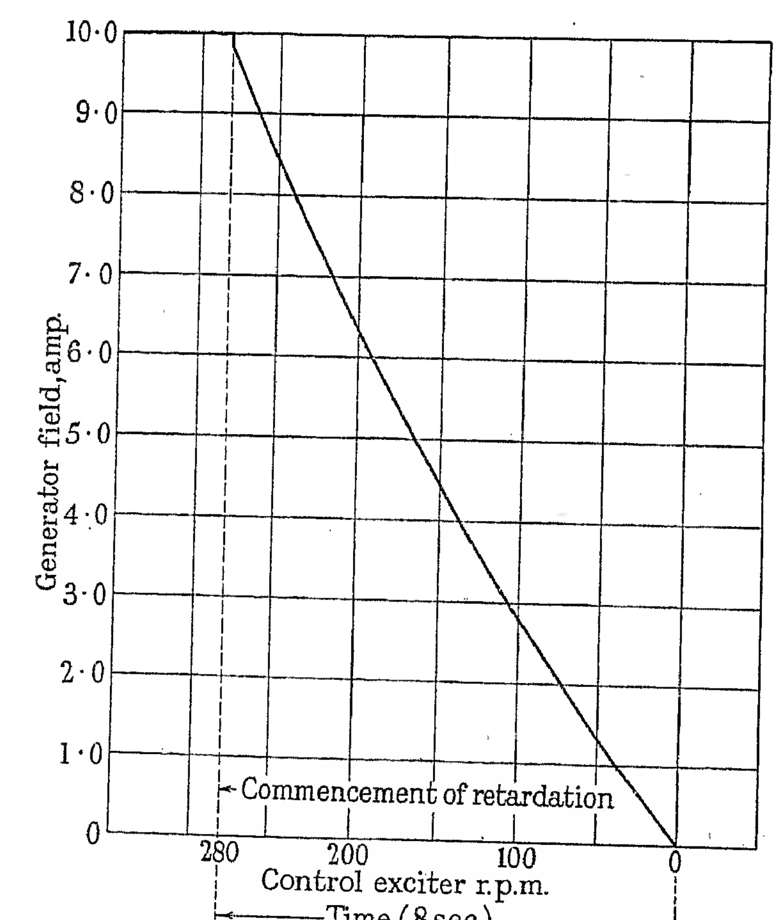


Fig. 2.—Gifford's Hoist, Champion Reefs. Variation of generator field current with control exciter r.p.m., with loaded " up " cage at 3 133 ft. from collar.

r.p.m. to produce a constant retardation of 4 ft. per sec. per sec. with a fully-loaded up-cage at a point 3 133 ft. from the collar of the shaft. Fig. 3 shows the generator field current plotted against control exciter r.p.m. to produce a constant regenerative current which will not exceed the peak capacity of the machine with a fully-loaded down-cage at a point 3 133 ft. from the collar of the shaft.

In the case of Gifford's winder the control exciter is connected to the drum shaft through a 10 : 1 increasing gear, therefore Figs. 2 and 3 also represent the output characteristics of the control exciter at the corresponding drum speeds when the down-cage is respectively 500 ft. and 3 133 ft. from the collar. As the degree of generator field magnetic saturation is the same in both cases and the increase in generator speed is not widely different, the general shapes of the characteristics are very little different.

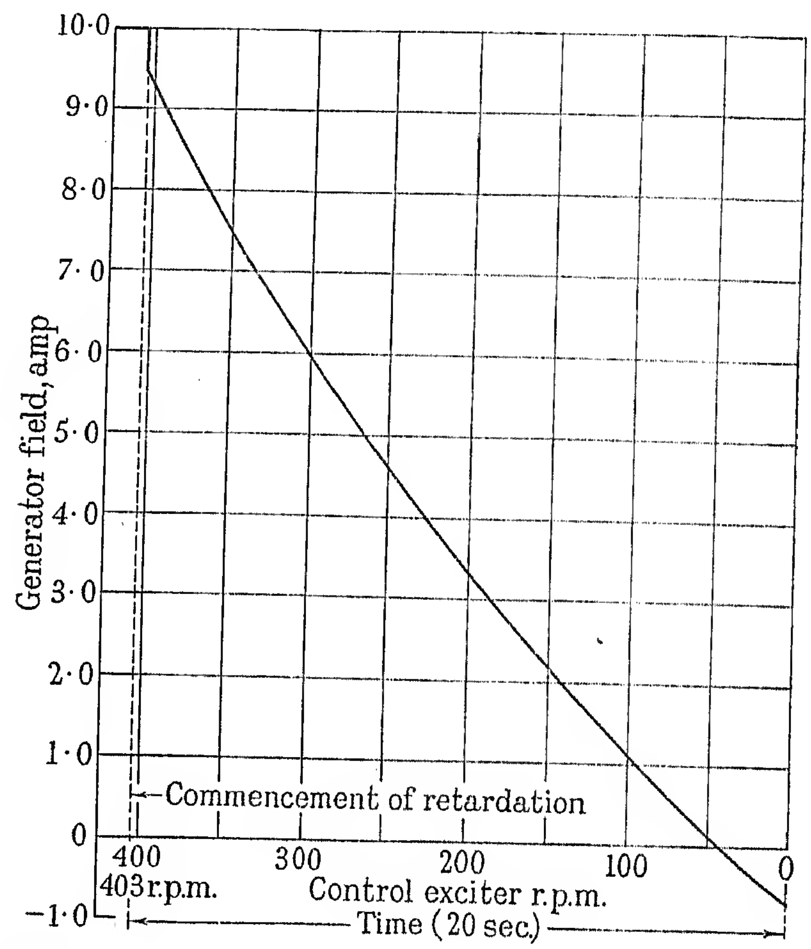


Fig. 3.—Gifford's Hoist, Champion Reefs. Variation of generator field current with control exciter r.p.m., with loaded " down " cage at 3 133 ft. from collar.

Field Mixing

It is obvious that an exciter with an entirely self-excited field winding cannot provide the correct characteristic shape, as the armature output falls very rapidly with the speed and collapses entirely, long before zero speed is reached. On the other hand an exciter with an entirely separately excited field would provide a straight-line characteristic which, although probably being suitable for a generator working at low saturation and driven at constant speed, would be entirely unsuited to a generator with characteristics as shown in Figs. 2 and 3. However, by providing the control exciter with two field windings and by suitably mixing the proportions of self to separate excitation, practically any desired exciter output characteristics may be obtained. In the exciter designed for Gifford's hoist the proportions adopted were 57 % self and 43 % separate excitation.

(2) CONTROL RESISTANCE

In Fig. 2 it will be seen that the demand from the exciter is 9·8 amp. at 280 r.p.m., whilst in Fig. 3 it is 9·5 amp. at 403 r.p.m. It is obvious therefore that, although the proportion of self to separate excitation must remain the same in both cases, the total excitation in the latter case must be less to compensate for the increased speed. This is brought about by making one end of each field winding common and inserting resistance in this common lead progressively during the wind. As the difference in depth between the relative positions of the cages in the two cases shown in Figs. 2 and 3 is a definite amount, as is also the necessary amount of resistance inserted in the exciter field, it follows that the increase of resistance is proportional to the distance travelled by the cages, and therefore the control resistance may be operated by the usual depth indicator or its driving mechanism. In Gifford's hoist the difference in depth between the two cases given above is 2 633 ft., and the variation in field resistance necessary to produce the required characteristics is 67·4 ohms. The total depth of the wind being 3 633 ft., the total variation in resistance between the beginning and end of a wind is (3 633/2 633) × 67·4 = 93 ohms. In Fig. 4 is shown the method of connecting the control exciter field circuits and control resistance.

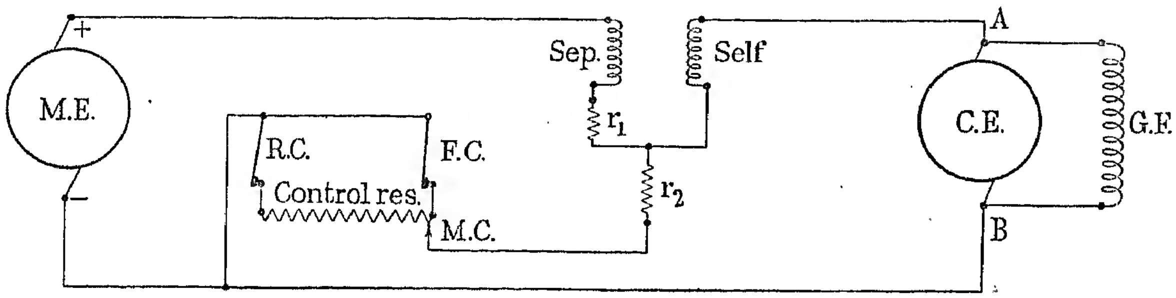


Fig. 4

M.E. = main exciter.
C.E. = control exciter.
Sep. = separately-excited field winding.
Self = self-excited field winding.
r_1 = resistance for making adjustments in field mixing.
r_2 = resistance for adjusting total excitation of control exciter and thus altering the characteristics as regards time, if necessary.
G.F. = main generator field.
C.R. = control resistance.
M.C. = moving contact in above.
F.C., R.C. = contacts in the forward and reverse contactors.

F.C. and R.C. are connected at opposite ends of C.R., so that when R.C. opens with the operation of the contactor necessary for the reverse wind, F.C. remains closed; the connection is therefore through F.C. to M.C. with the minimum of resistance, as is required at the beginning of the wind. As the reverse wind progresses M.C. moves along C.R. towards the left, inserting resistance progressively. The extreme left is reached at the end of the wind. At the commencement of the forward wind F.C. opens, leaving R.C. closed, and the whole procedure is reversed. The method of connecting the two field windings as shown, whilst simplifying their control has an effect on the exciter armature current and thus on the generator field. This effect can be compensated for in the design of the exciter, but this is outside the scope of the present paper and the author does not propose to discuss it here.

There is no reason, however, why each field circuit should not be kept completely separate each with its own control resistance, when the complications in the exciter design disappear. Doing this, however, makes the switching of the control resistance more complicated.

Control with Bi-cylindro-conical Drums

The static torque curve on hoists with such drums is not a straight line as is the case with cylindrical drums, but is a curve generally of the type shown in Fig. 5. It will be seen that the portion of the curve from B to C is of exactly the same nature as the torque line with cylindrical drums, consequently the control resistance will vary in exactly the same way as with cylindrical drums, that is from zero at B to a maximum at C. The actual beginning of the wind with the bi-cylindro-conical drums is at A, and as the static torque at A is the same as that at a point F later in the wind the control resistance

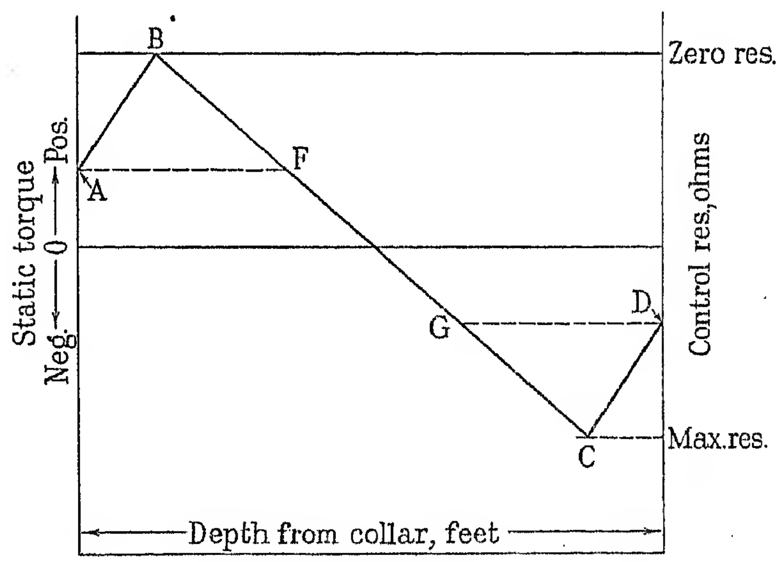


Fig. 5

must start the wind at a value equal to that required at F. It must then decrease to zero when B is reached, when it must increase progressively to a maximum at C, when, as the static torque again begins to decrease, the resistance must also decrease to D, which is equivalent to a point G earlier in the wind. These changing values of resistance are obtained quite simply by arranging the control resistance in a somewhat different way from that for cylindrical drums. This is shown in Fig. 6. In the diagram it is assumed that the reverse contactor R.C. has operated leaving the feed to the control resistance through

F.C. to B, and M.C. is assumed to move to the left as the wind progresses.

At the beginning of the wind M.C. is on the first contact A, which is connected to a point on the resistance F giving the required resistance at starting. As M.C. moves along towards B, the resistance is reduced in the proper order until at the point B the resistance is zero as required. As M.C. moves further along, the resistance is progressively increased until a maximum is reached at C. Further movement to the left now reduces the resistance until at the end of the wind at D, which is connected to the resistance at a point G, the resistance is at the value of point G.

(3) APPLICATIONS OF CONTROL EXCITER IN REGENERATIVE EMERGENCY BRAKING

Having now obtained a machine which will provide the generator field-current/winder r.p.m. characteristics for the two extreme conditions of loading, it is necessary to discuss the requirements for its proper application.

(*a*) In order that the winder may be reversible it is of course necessary to reverse the polarity of the generator

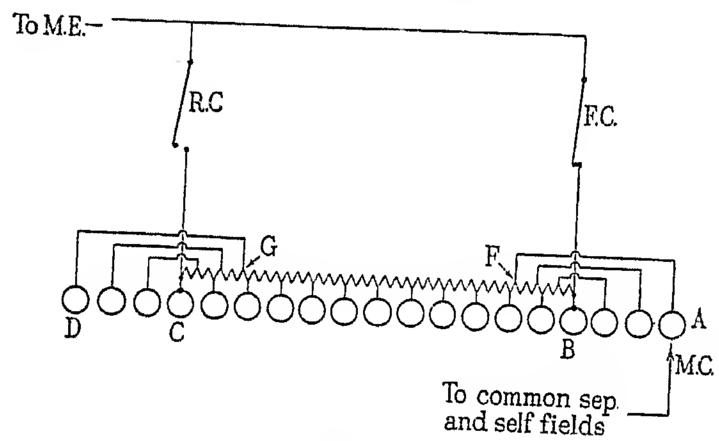


Fig. 6

field, and, as the control exciter is shunted directly across this field winding this must be reversed at the same time. The control exciter field is unidirectional in both winds, therefore the control exciter armature e.m.f. reverses automatically with the change of rotation. This armature and the generator field may therefore be treated as one unit and connected when necessary to the main exciter through forward and reverse contactors (direction contactors). The points which are reversible are shown at A and B in Fig. 4.

(*b*) When the hoist is at rest and the above-mentioned contactors are in the off position, the generator field is connected across its armature in such a way as to kill residual magnetism in the generator. These are known as the "suicide connections." One or the other of the above contactors is moved to the "on" position by a magnet coil whose circuit is closed by contacts on the driver's control lever. Now if an emergency occurs, suicide connections must not be made, otherwise the generator field will be killed. Whichever contactor is in the "on" position, therefore, must remain so, even though the driver should injudiciously move his control lever to neutral whilst the winder is retarding during emergency. It is therefore necessary during emergency to short-circuit the direction contactor selector contacts on the driver's control lever, until it is safe for suicide contacts to be made.

(*c*) It is necessary to cut off the supply from the main exciter through the Ward–Leonard controller to the generator field in order that the generator field may be supplied and controlled, according to the necessary characteristic, by the control exciter. This is brought about by inserting the regenerative emergency contactor in the positive lead from the main exciter to the generator field. The various protective devices which operate under conditions that permit regenerative braking are connected in series with the hold-in coil of the above contactor.

(*d*) It is necessary to keep the brake magnet solenoid energized until the speed of the winder has been reduced to a point at which it is desired to apply the mechanical brakes to bring the winder to rest.

(*e*) It is necessary to keep the motor field current at its maximum value during retardation. The motor field economy contactor is usually operated by contacts on the driver's lever which either close or open the contactor coil circuit. To obviate the possibility of the motor excitation being reduced during retardation by the driver injudiciously moving his control lever to neutral, contacts are placed on the direction contactors which either short-circuit the economy contactor operating contacts or maintain the circuit open, as the case may be.

In emergencies in which regenerative braking is not permissible, such as overspeed of convertor set, field failure, and overwind, it is necessary for the mechanical brakes to be applied at once. In these cases, therefore, the non-regenerative emergency contactor is placed in the main lead from the main exciter. The protective devices which operate under the above conditions are thus connected in series with the hold-in coil of this contactor. When this operates, excitation is removed from all machines and the brake solenoid.

Voltage Relay

In order to provide for the requirements of (*b*) and (*d*) above, a voltage relay is provided which is arranged to pull in immediately after one or the other of the direction contactors has been selected. The relay is held in by a coil connected across the control exciter armature, and its strength can be so adjusted that when the control exciter voltage and thus the speed of the winder has dropped to any desired value the relay pulls out. On pulling in, the voltage relay closes contacts which short-circuit the whole of the selector contacts on the driver's lever. In order to prevent the other direction contactor from being pulled in, each direction contactor pull-in coil is connected in series with contacts on the other contactor, which open as the latter contactor moves to the "on" position. The one contactor coil is therefore open-circuited when the other contactor is in the "on" position.

In addition to the above short-circuiting contacts, the relay closes contacts which are connected in series with the brake-magnet solenoid. It is, of course, not desired that the brake-magnet solenoid should be de-energized during normal service, and as the voltage relay operates at every wind the above contacts are themselves short-circuited by contacts on the regenerative emergency con-

tactor. This is shown simply in Fig. 7, where R.E.C. is the regenerative emergency contactor, V.R. the voltage relay, and B.S. the brake solenoid.

Effects of Varying Load

In Fig. 2 is shown the characteristic required to decelerate the hoist in a given time early in the wind with a fully-loaded up-cage. The result of the reduction in generator field current in this case is to reduce the driving torque of the motor, the torque producing retardation being provided by the suspended upcoming rope, cage, and load. If the load is reduced or if a load is put in the down-cage the retarding torque is decreased, with a consequent increase of retardation time. The maximum reduction in retarding torque, and consequent increase in time, will occur with an empty up-cage and a fully-loaded down-cage. This is as it should be, as owing to the decreased rate of retardation the retarding stresses on the loaded down-rope are reduced. Now in the case of a trip late in the wind, the effect of the reduction in generator field current is to produce a retarding torque at the motor over and above the static torque at the moment. In Fig. 3 the characteristic is designed to produce a certain deceleration with a maximum of negative static torque due to a fully-loaded down-cage and rope, with the up-cage empty. If the load in the down-cage is reduced or if a load is put in the up-cage, the negative static torque is reduced, with the result that the retardation torque provided by the motor results in a greater rate of retardation, with a consequent reduction in retardation time. Thus the deceleration time may vary between the two limits set, and is automatically controlled by the magnitude and direction of the cage loads.

(4) APPLICATIONS OF CONTROL EXCITER IN NORMAL SERVICE

The usefulness of the control exciter is not confined to emergency conditions only, but can be applied to the controlling of acceleration and deceleration in normal service. With existing Ward-Leonard winders, when accelerating or decelerating at a point in the wind at which the normal cams are out of action there is nothing to prevent the driver from accidentally or injudiciously moving the control lever too fast or too far. There are certainly devices in service which trip the winder on this occurring. These, however, do not prevent a proportionately large increase or decrease of current flowing in the generator and motor armature, with consequent rapid acceleration or deceleration, but only prevent the continuation of such current.

The action of the control exciter during acceleration is as follows. From Fig. 1 it will be seen that the control exciter armature constitutes a low resistance in parallel with the comparatively high resistance of the generator field. On the Ward-Leonard controller being moved to any given point, which of course corresponds to a definite speed of the winder, the current in the generator field cannot rise immediately to the value corresponding to this speed, as the current divides between the parallel paths of generator field and control exciter armature, the major portion of the current passing through the latter. As the winder and control exciter begin to rotate, the armature of the latter generates a back-e.m.f. which raises the voltage across its terminals. This means that the voltage across the generator field is raised and the field current is increased accordingly. Owing to the increased field current the winder and control exciter accelerate further and also the exciter back-e.m.f. increases, and so the process is progressive until a point of balance is reached at the speed corresponding to the controller setting. Much greater latitude in the movement of the control lever is therefore permissible.

The action in the case of deceleration is as follows. The deceleration characteristics (Figs. 2 and 3) for two points of the wind have been discussed earlier, and as the control exciter has been designed to provide these characteristics, if by moving the control lever too far towards neutral the supply from the main exciter to the generator field is reduced below the value required at a given winder speed, the control exciter will supply the balance of current, the winder then retarding according to the characteristic until a point of balance is again arrived at where the speed corresponds to the new controller position. In other words, irrespective of how far the control

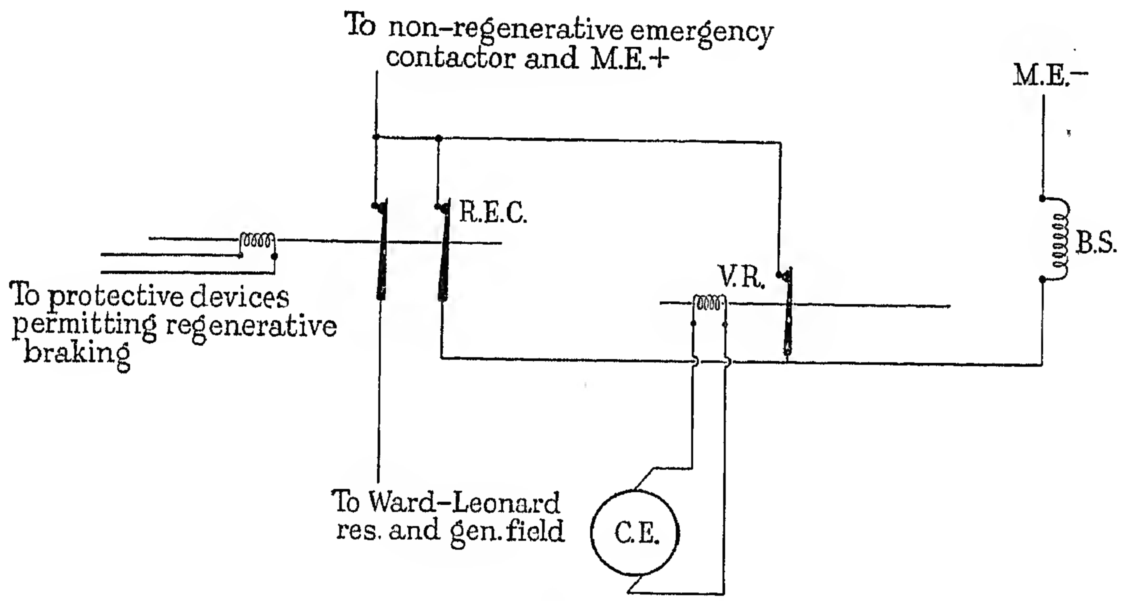


Fig. 7

lever is moved the winder cannot decelerate at a rate greater than the designed characteristic of the control exciter will allow. In fact the control lever may be returned completely to neutral, the result being that the winder behaves exactly as it would in an emergency trip, with the exception that the brake solenoid is not open-circuited, by reason of the fact that the regenerative emergency contactor has not been operated.

(5) RESULTS AT GIFFORD'S SHAFT

The whole of the apparatus for the system was made in the local workshops, and the fitting of this and the change-over to the new system was done with only a few hours' interruption to service. Considering the fact that it was the first of its kind, very little trouble was experienced in getting it correctly adjusted. From the decelerometer records taken it is found that the deceleration times under test agree very closely with those calculated. From these records it is also noticed that, even with regenerative braking, much more rope oscillation is caused by the application of the mechanical brakes just before coming to rest than is caused by the regenerative braking itself. In a trip with mechanical emergency braking, although the actual braking time is 4·4 sec., the time from the actual emergency trip to the winder coming to rest is 6·5 sec., there being a delay of approximately 2 sec. before the actual application of the brakes.

In normal service using the author's system the greatly increased latitude in the movement of the control lever is very marked, there being no sudden heavy rush of current when, during acceleration, the control lever is moved even as far forward as three-quarters full travel from neutral, but the winder accelerates smoothly up to the corresponding speed. Similarly, on moving the control lever from full speed straight to neutral the winder decelerates smoothly to creeping speed and remains at this speed until further movement of the lever, or until the mechanical brakes are applied to bring it to rest. The normal acceleration and deceleration has in no way been interfered with.

It is the fact that the apparatus is in continuous service during normal operation of the winder, and does not have to wait until an emergency occurs before doing any work, that is, in the author's opinion, a very strong point in its favour as an emergency device. Should any fault develop, it is immediately apparent during normal working; in fact the winder could not be worked at all with any fault on the control exciter with the exception of an open-circuit in the exciter armature circuit, which would be immediately reflected on the loss of that latitude of movement in the control lever which is so apparent with the use of the system. Furthermore, whatever type of fault should develop on the control exciter, emergency braking is immediately thrown back on to the mechanical brakes.

The calculated variations of deceleration time for Gifford's winder are as under:—

		Calculated, sec.	Actual, sec.
Fully-loaded up-cage.	Beginning of wind (up-cage 3 133 ft. from collar).	8	8·6
Fully-loaded up-cage.	End of wind (up-cage 500 ft. from collar).	9·5	10
Fully-loaded down-cage.	Beginning of wind (down-cage 500 ft. from collar).	14	15
Fully-loaded down-cage.	End of wind (down-cage 3 133 ft. from collar).	20	20

ACKNOWLEDGMENTS

The author is indebted to Messrs. John Taylor and Sons, who kindly granted facilities for carrying out the experimental work involved in the development of this control system; to the Mine Superintendent of the Champion Reef Gold Mines of India, Ltd., for permission to install it at Gifford's Shaft, Champion Reefs; and to the Chief Electrical Engineer, Kolar Gold Field Electricity Department, for valuable advice and assistance.

FIRE-FIGHTING EQUIPMENT FOR ELECTRICAL INSTALLATIONS*

RECOMMENDATIONS OF THE BRITISH ELECTRICAL AND ALLIED INDUSTRIES RESEARCH ASSOCIATION

SUMMARY

It has been realized for some time that fire risk in electrical installations involves special consideration owing to the nature of the combustible materials involved. Preliminary study of the problem resulted in the risks being divided into four categories, and a series of tests was undertaken with varying available media and different installations in each category. This paper describes briefly the test installations designed and erected for this purpose and gives a general outline of the testing technique involved.

Tables are given showing the results of the tests, with explanatory notes where necessary for each test. The paper concludes with a discussion of the test results, and general recommendations are given in regard to the various categories of risk tested.

CONTENTS

CONTENTS—*continued.*

(1) INTRODUCTION

As an outcome of various fires that had occurred in electrical installations in different parts of the country, it was decided to carry out a number of tests in order to investigate the limitations and useful fields of application of methods of fire extinction available on the market. It was realized from the outset that it would be impossible to create on a test ground all the combinations that might occur in practice, owing to the large number of variables in the types of risk and in the conditions which occur when a fire takes place. Before deciding upon a programme of tests, much consideration was devoted to the hazards involved in the various component parts of power installations. It was felt, however, that tests on the more serious risks would give results from which conclusions could be drawn which would cover all normal installations, particularly if the test installations were so arranged as to reproduce the most severe conditions likely to occur in any individual fire. It was therefore decided to carry out in the first place tests on the following risks:—

- (a) Transformer banks, etc., exposed to the atmosphere.
- (b) Transformers, etc., in buildings.
- (c) Cable tunnels and ducts.
- (d) Cable runs or ducts exposed to the atmosphere.

Test installations to represent these conditions were

* Official communication (Ref. V/T8) from the British Electrical and Allied Industries Research Association.

The Papers Committee invite written contributions, for consideration with a view to publication, on papers published in the *Journal* without being read at a meeting. Contributions (except those from abroad) should reach the Secretary of The Institution not later than one month after publication of the paper to which they relate.

designed and erected, and arrangements were made to apply to them the various types of extinguishing installations available on the market.

Fig. 1 shows a layout plan of the installation at Barking on which the tests were made.

(2) TEST INSTALLATIONS

(a) Transformer Banks, etc., Exposed to the Atmosphere

For carrying out tests on this category of apparatus, a special installation was made, known throughout the paper as the " outdoor oil fire " (Fig. 2).

Provision was also made to admit water under pressure to the bottom of the tank and so vary the height of the oil level during a test, even to the extent of making it overflow the top edge of the tank before or during the course of the fire.

Electric heaters were installed to preheat the oil before a test.

(b) Transformers, etc., in Buildings

A concrete building 10 ft. by 12 ft. by 10 ft. (Fig. 3) was erected for the purpose of these tests. The normal ventilation was provided by six 9 in. × 3 in. hit-and-miss ventilators at the bottom and six equivalent air

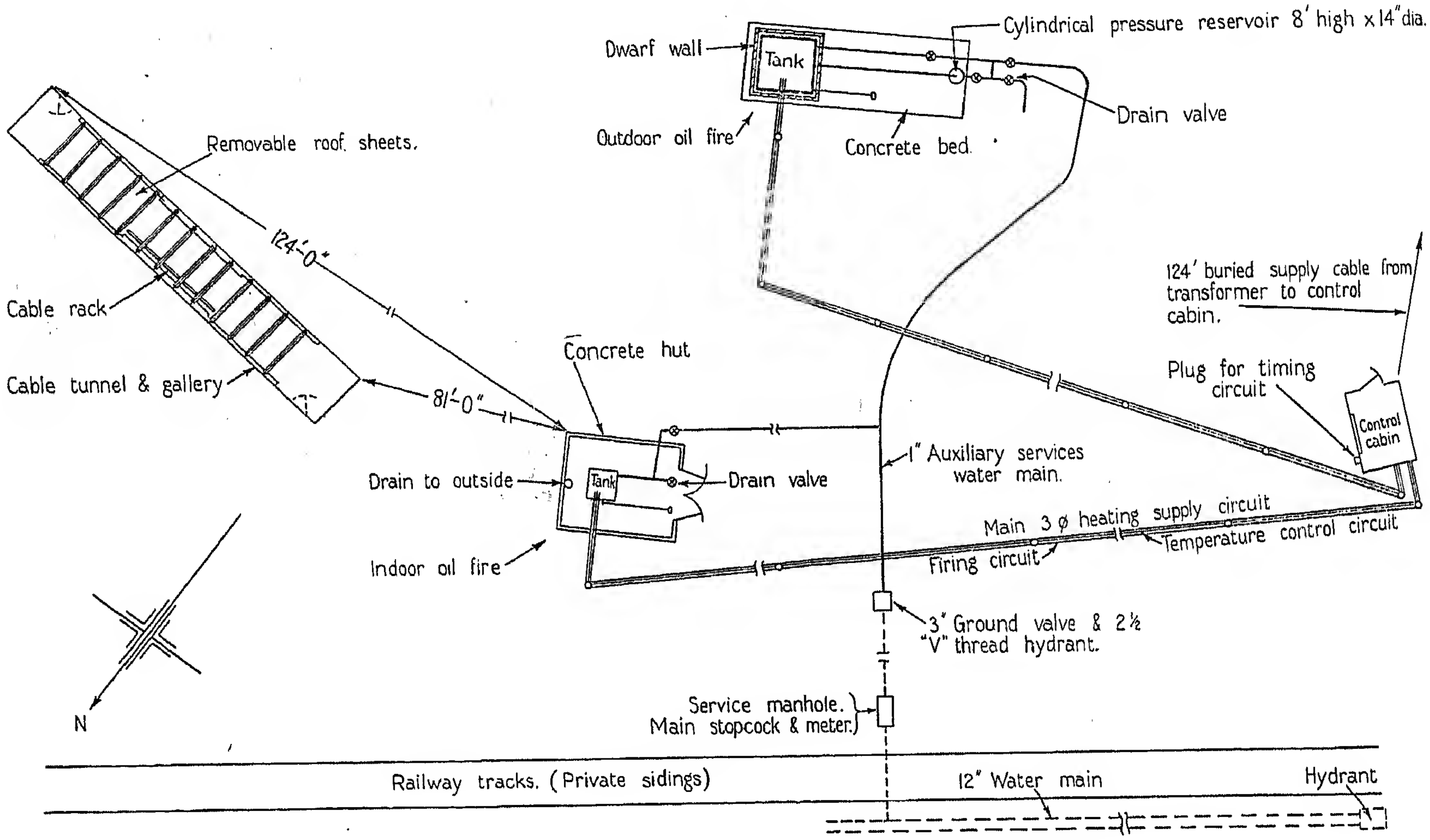


Fig. 1.—Layout plan of installation for E.R.A. fire tests at Barking.

The transformer comprised a tank 5 ft. 6 in. square and 3 ft. deep, erected on an angle-iron framework with the top edge of the tank 10 ft. from ground level. Round the sides of this tank, reaching to within 1 ft. 6 in. of the ground, were nests of tubes designed to represent the cooling tubes of normal transformers. The normal quantity of oil tested in this tank was 360 gallons. To represent the conditions arising from a burst or a split the tank was provided with a restricted drainage tube through which a known quantity of oil could be released into a pit formed by dwarf walls.

Arrangements were made so that, during the course of the tests, jets of oil under pressure issued from a pipe round about the top of the cooling tubes in order to represent pressure leaks which might arise through the disappearance of a cover gasket accompanied by a pressure-rise inside the transformer, or by leaks due to oil falling down from a conservator at a higher level.

bricks at the top. The building was provided with doors at the front and a ventilating flap at the back which could be adjusted so as to allow a certain amount of additional ventilation in the chamber.

The oil tank used to represent a transformer, etc., in this building was similar to that used for the outdoor tests, except that it was not provided with cooling tubes on the outside. The normal quantity of oil used on a test on the indoor transformer was 60 gallons.

(c) Cable Tunnel

For this category of fire a special building was erected comprising two parallel walls 32 ft. long by 6 ft. 4 in. high and 6 ft. 4 in. apart (Fig. 4). The roof of this tunnel was made removable. The ends were closed by doors.

Cable racks were fitted alongside the centre portion of one of the walls of this tunnel, and this centre portion

only was used for actual fire tests in order to avoid any end effects due to doors and other conditions.

The cables laid in the racks were of the 33-kV single-core paper-insulated lead-covered and jute-served type. Lengths of 19/·064-in. and other smaller-section vulcanized-rubber cables were added to represent wiring for control or auxiliary circuits.

mately 50 gallons were allowed to flow into the pit through the drain tube.

In the case of automatic protective installations electrically operated firing was employed, firing taking place in five places simultaneously to ensure rapid spread. Hand firing was sometimes used when more convenient for the delayed manual tests.

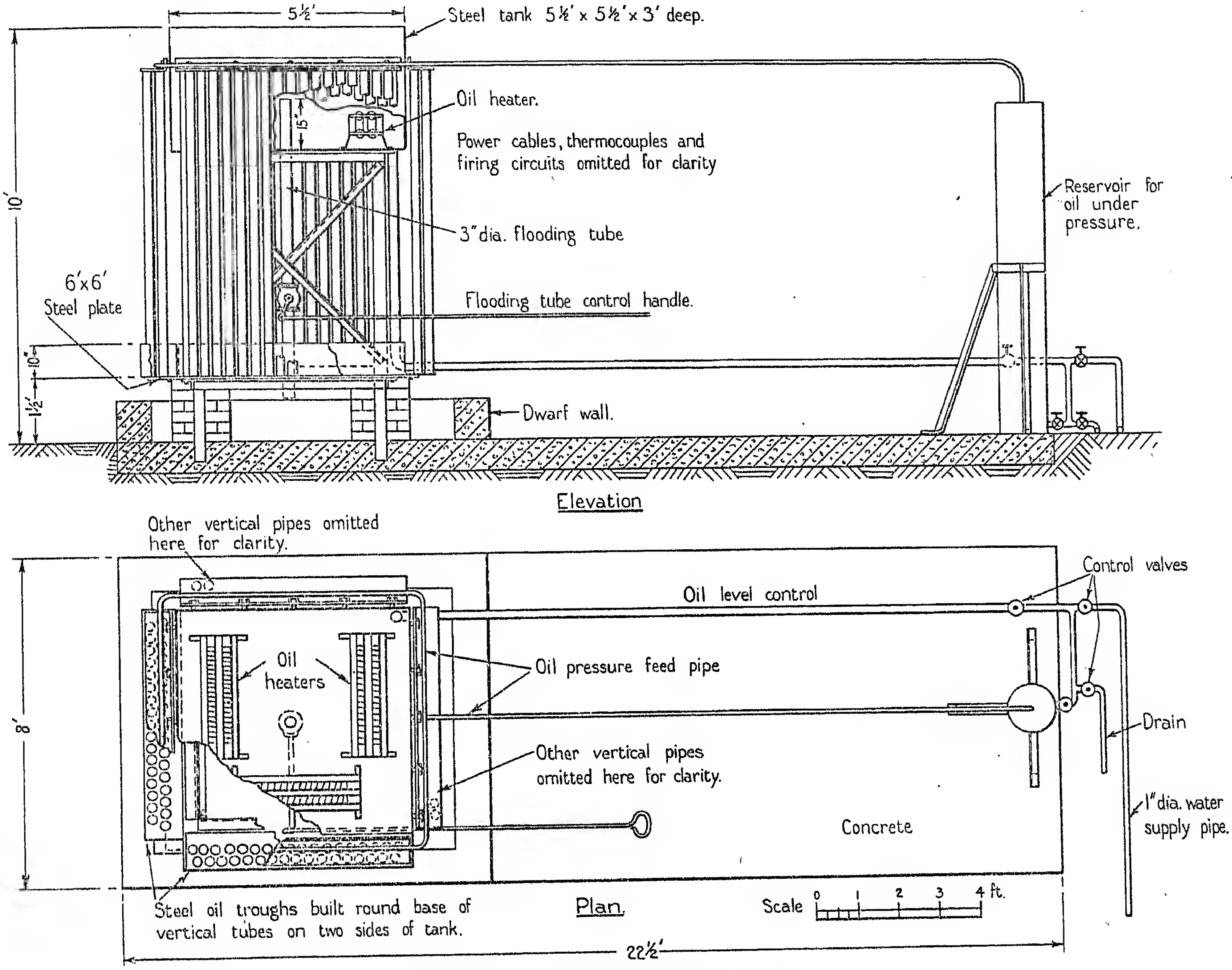


Fig. 2.—E.R.A. outdoor oil-fire test tank.

(d) Cable Gallery

The brick building erected for carrying out cable tunnel tests was also used for the cable gallery tests. In the latter case the roof was removed in order to comply with the conditions of cable ducts and runs where sealing from the outside atmosphere is not possible, and to simulate as nearly as possible the conditions which may obtain in power stations or substations where cables are laid along walls in a fairly high room.

(3) TESTING TECHNIQUE

(a) Outdoor Oil Fires

The oil in this tank was preheated electrically to its flash point (approximately 315–320° F.). The quantity of oil used was normally 360 gallons, of which approxi-

As soon as the oil was ignited it was caused to overflow the top of the tank, and jets of oil under pressure were made to issue from the pipe round the top of the tube.

At the joint request of those manufacturers who proposed inert gases for this risk, screens were erected round three sides of the transformer. These screens were subsequently removed before other types of media were used.

(b) Indoor Oil Fires

The oil in the tank was also preheated electrically to its flash point. The quantity of oil used normally was 60 gallons, of which 20 gallons were allowed to flow over the floor through the drain tube.

In the case of automatic protective installations elec-

trically operated firing was employed, firing taking place in three places simultaneously. In the case of delayed manual operation the fires were sometimes ignited electrically and sometimes by hand.

(c) and (d) Cable Tunnel and Gallery

The technique employed for tests in the tunnel or gallery consisted in wrapping a small quantity of hessian round the two lower cables in two or three places. These hessian coverings were soaked in transformer oil and ignited by means of a petrol-soaked wad carried on the end of a rod approximately 8 ft. long. Immediately before the test about 5 gallons of transformer oil was splashed over the cables and the wall, to represent projection of cable oil due to a blow-out type of fault. The fires were allowed to burn freely until either the automatic gear came into operation or the signal for operation was given.

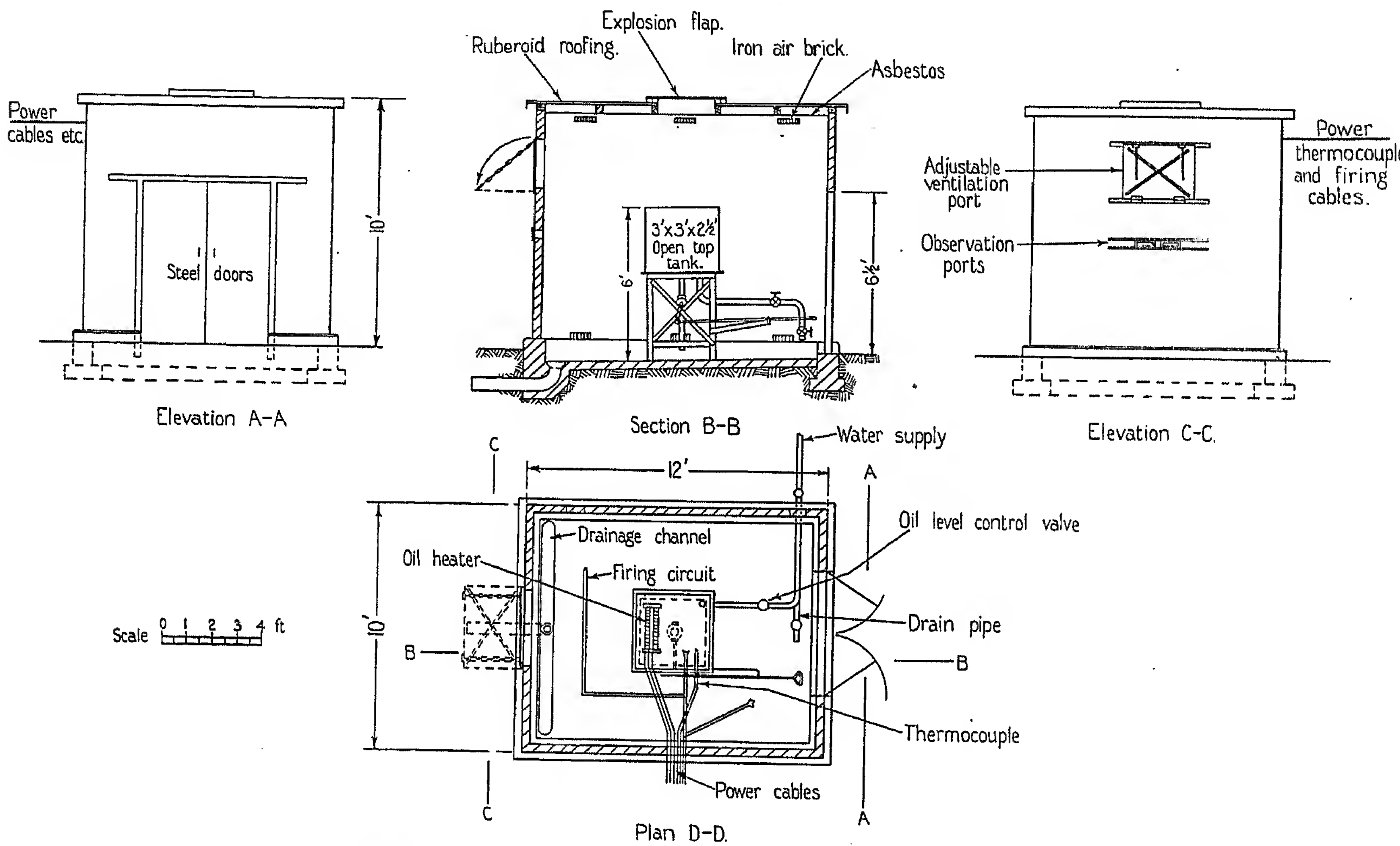


Fig. 3.—Building for E.R.A. indoor fire tests at Barking.

(4) TYPES OF MEDIA USED

Tests were carried out with methyl-bromide gas, carbon dioxide, mechanical foam, chemical foam, and water, applied in accordance with the various manufacturers' conceptions. All collaborating firms were given an entirely free hand in regard to their installation details and the quantities and composition of media used. Exact records were kept and are reproduced in the detailed report of the tests (Ref. V/T7).*

* Obtainable from the British Electrical and Allied Industries Research Association.

(5) TESTS CARRIED OUT

The tests carried out were divided into three categories:—

(*a*) With fixed installations and fully automatic features where these were provided. This type was tested on the outdoor, indoor, and cable-tunnel installations.

(*b*) With the same installation, but without any automatic features. In this case the fires were allowed to burn for a period of 2 minutes 30 seconds, which was, however, varied according to circumstances in order to provide a fire of similar intensity in all comparable tests. The signal was then given to discharge the particular medium used for extinction. This type was tested in all four installations.

(*c*) With portable devices—this type was only tested in the outdoor and the cable-gallery installations.

In the indoor installation, in order to try the effect of different degrees of ventilation, some tests were made with the ventilating flap open and the doors closed, whilst others were made with the flap closed and the doors open. Sufficient information was obtained on the earlier forms of medium to make it unnecessary to test the later forms under all the various conditions.

(6) TIMING

Wherever possible, these tests were timed by means of a special synchronous timing clock, which could be included in the photographs.

(7) CINEMATOGRAPH RECORDS

Where lighting and other conditions made it possible, 16-mm. cinematograph films were taken during the tests and have proved very valuable in analysing the results obtained.

(8) TYPES OF MEDIA TESTED

Broadly speaking, fires of this nature may be extinguished in one of two ways or by a combination of them. In the first place a fire may be extinguished by depriving the source of inflammable material of any supply of oxygen, and in the second place it may be extinguished by cooling the burning material to a temperature below its point of ignition.

Inert gases such as methyl bromide and carbon dioxide cause extinction by exclusion of oxygen, the cooling effect being practically negligible. Water, on the contrary, causes extinction by cooling. Foam causes extinction mostly by its smothering effect, thus excluding the supply of oxygen, and to a relatively small extent by its cooling action.

The primary object of this work was to investigate the limitations and useful fields of application of the various fire-fighting media available. The number of different variations of each type of medium taken in conjunction with the number of firms dealing in these products was too great to make it practicable to carry out tests on any and every combination. Representative firms were selected and were invited to apply the various media in accordance with their own conceptions.

The actual types of media tested were as follows, duplicate tests by different firms being made where possible:—

(*a*) *Inert Gases*:—

(i) Methyl bromide.
(ii) CO_2.

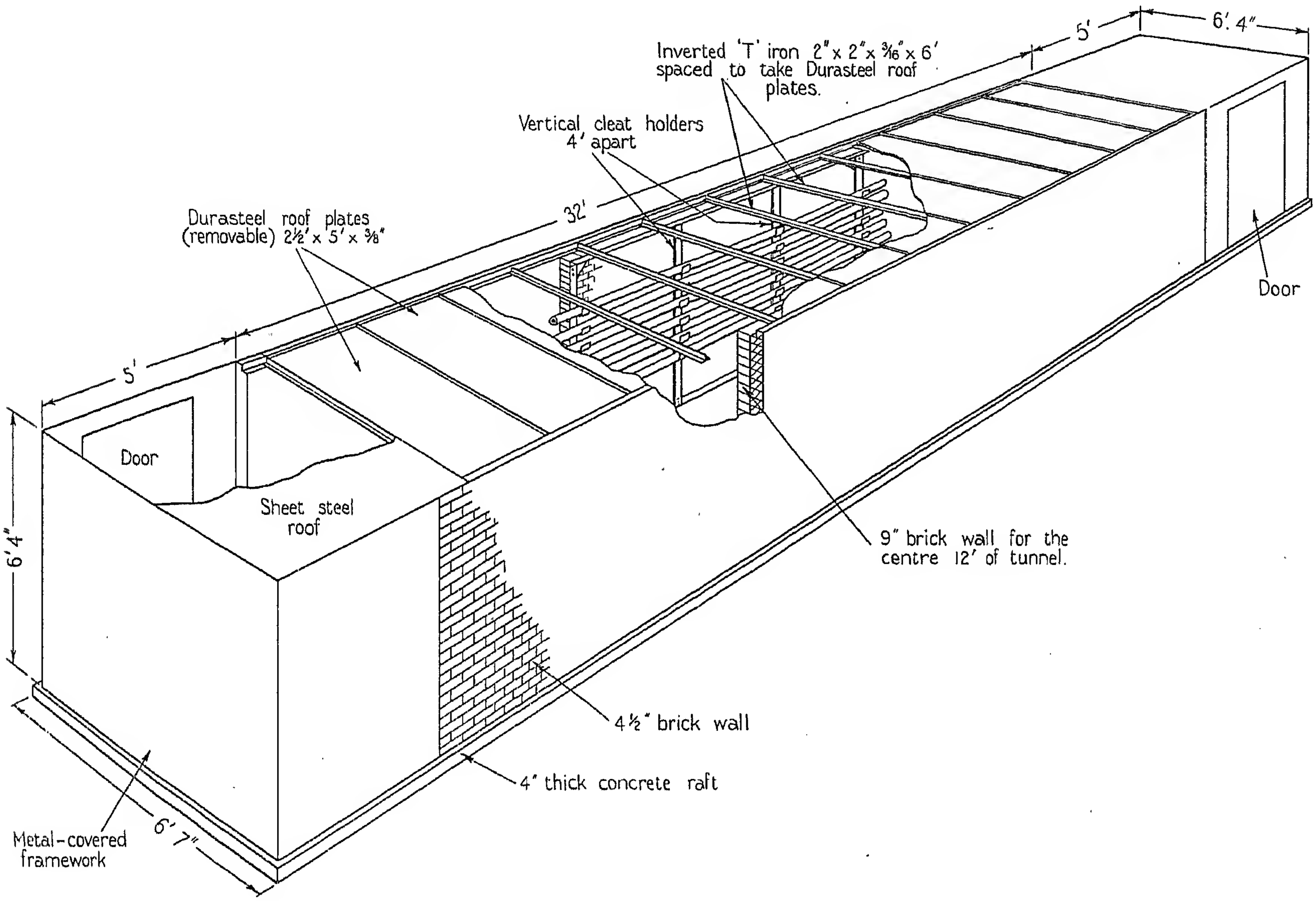


Fig. 4.—E.R.A. tunnel and gallery for cable-fire tests.

(*b*) *Foams*:—

(i) Mechanical.
(ii) Chemical.

(*c*) *Water*.

(9) TEST RESULTS

The test results are set out in Tables 1–9. They give the significant figures obtained during the course of the tests and are accompanied by brief notes on the circumstances and various occurrences which took place. Care should be exercised in using such abbreviated notes, and reference should be made to the corresponding test in the full report (Ref. V/T7)* to ensure that all the circumstances are fully considered.

* Obtainable from the British Electrical and Allied Industries Research Association.

Table 1

Type of Risk: Cable Tunnel.
Type of Operation: Automatic.
Type of Installation: Fixed Nozzles.

Test number	Type of medium	Manu-facturer's designa-tion	Weather conditions					Time, in minutes and seconds		Quantity of medium discharged, lb.	Result of test
			Wind		Tempera-ture, °F.	Pressure, millibars	Humi-dity, %	Burning before start of discharge	Discharge		
			Direction	Speed, m.p.h.							
4	Methyl bromide	A	NNW.	8–12	49	1 008·8	83	—	—	—	No fire (see Note)
12	CO_2	B	—	Nil	71	1 014·5	75	– 11	– 30	100	Fire extinguished
21	CO_2	C	WSW.	3–5	75	1 012·1	75	– 15	1.28	100	Fire extinguished

Notes on Table 1 :—

Test No. 4.—Owing to the extremely rapid action of the smoke-detection device which was operated automatically by the smoke from the firing wad during attempted ignition, no fire was obtained. It was agreed to disconnect the automatic gear and to carry out the test with delayed manual operation (see Test No. 6, Table 2).

General Remarks :—

Owing to the fact that when water and foam installations are properly designed they are not sensitive to draught conditions, it was considered that the data obtained in the cable gallery tests with water and foam were sufficient to enable the tests of these media in this cable tunnel to be dispensed with.

Table 2

Type of Risk: Cable Tunnel.
Type of Operation: Delayed Manual.
Type of Installation: Fixed Nozzles.

Test number	Type of medium	Manu-facturer's designa-tion	Weather conditions					Time, in minutes and seconds		Quantity of medium discharged, lb.	Result of test
			Wind		Tempera-ture, °F.	Pressure, millibars	Humi-dity, %	Burning before start of discharge	Discharge		
			Direction	Speed, m.p.h.							
6	Methyl bromide	A	NNW.	8–12	49	1 008·8	83	2.45	– 18	24	Fire extinguished
15	CO_2	B	—	Nil	71	1 014·5	75	2.0	– 39·5	100	Fire extinguished
22	CO_2	C	WSW.	3–5	75	1 012·1	75	2.30	1.33	100	Not completely extinguished (see Note)

Notes on Table 2 : —

Test No. 6.—Heat developed during the 2 min. 45 sec. delay caused 2 in. × 2 in. × ⅜ in. T bars in roof to sag slightly. Fire fierce.

Test No. 15.—Signal for discharge given at 2 min. as fire had reached the usual intensity at that time. Low visibility prevented exact time of extinction being recorded.

Test No. 22.—Normal-intensity fire. Main fire extinguished, some smouldering parts remaining. Smouldering parts removed by hand to prevent flashback. Quicker discharge might have succeeded better.

(10) DISCUSSION OF TEST RESULTS

(a) Outdoor Oil Risks (Transformer Banks, etc., Exposed to the Atmosphere)

The various forms of fire-fighting media applied to this particular risk were water, CO_2, methyl bromide, and foam.

Apart from the back-up tests applied by the fire brigades, there were two tests with water on fixed-nozzle installations with automatic operation, and four tests with fixed nozzles and delayed manual operation. All these tests were, in general, successful. The quantity of water used varied from 145 to 900 gallons. The larger quantity mentioned was used in an effort to extinguish a fire which persisted on a piece of rag left in the nest of cooling tubes. Even with the larger quantity this rag had finally to be extinguished by hand. This experience indicates the desirability of special steps to prevent combustible material of this sort being left about in nooks and crannies of electrical equipment.

It should be noted that with the tests using water as the fire-extinguishing medium no screens were installed round the transformer. These screens do not therefore appear to be necessary from the point of view of fire-extinguishing, but they may be desirable in certain cases to avoid the risk of fire spreading from one piece of apparatus to another.

There were in all five tests with CO_2—two with fixed nozzles and automatic operation and three with fixed nozzles and delayed manual operation.

On Tests Nos. 23 and 27 the amount of CO_2 discharged

Table 3

Type of Risk: Cable Gallery.
Type of Operation: Delayed Manual.
Type of Installation: Fixed Nozzles.

Test number	Type of medium	Manufacturer's designation	Weather conditions: Wind: Direction	Weather conditions: Wind: Speed, m.p.h.	Weather conditions: Temperature, °F.	Weather conditions: Pressure, millibars	Weather conditions: Humidity, %	Time, in minutes and seconds: Burning before start of discharge	Time, in minutes and seconds: Discharge	Quantity of medium discharged, gallons	Result of test
28	Foam	C	SE.	13–18	61	1 005·2	92	2.30	2.22	800	Not completely extinguished (see Note)
32	Foam	D	WSW.	1–3	44	1 004·4	75	2.5	– 41	260	Fire extinguished
36	Water	E	SW'W.	8–12	60	1 007·9	75	2.15	– 42	94	Fire extinguished after second shot (see Note)
41	Water	F	SW'W.	8–12	47	1 015·4	75	2.5	– $6\frac{2}{5}$	13	Fire extinguished

Notes on Table 3 :—

Test No. 28.—Steam and smoke hindered visibility. Fire appeared to be out at 1 min. 6 sec. After shutting off foam supply it was noted that fire still persisted in centre section and right-hand extremity behind the cables. Foam discharged for a further 1 min. 16 sec. but still failed to cover back of cables near wall. Extinguished by hand by lifting and applying foam with shovel. The foam, which was rather thick, failed to build up behind cables; better positioning of nozzles and faster application with possibly a thinner foam would probably have got behind the cables. Danger spot in this type of risk appears to be in blind spaces. The jets used were of the directional type.

Test No. 32.—Installation based on entirely different conception from that in Test No. 28, a directional spreader being used instead of jets. Type of foam used also much thinner. Fire successfully extinguished. Type of installation used would demand great care in design in confined spaces, requiring multiple delivery points. In locations where other apparatus may be adjacent, precautions to avoid splashing and overflow of watery effluent should be considered.

Test No. 36.—In this case open sprinkler heads were used to cover the general risk, as opposed to directional nozzles covering the cable rack only. This type of installation covers any immediately close roof risk. During first discharge of 27 sec. the fire was thought to be out at 10·4 sec. from start of discharge. Inspection revealed smouldering; a second discharge was given for a further 15 sec., fire then completely extinguished.

Test No. 41.—The installation provided employed directional jets covering the cable rack and floor. It was not designed to cover the wall opposite the cable rack and was not directed upwards. Extinction was very rapid with a very small quantity of water. Slight modification of nozzle angle would possibly have proved an advantage.

was 350 lb. This is sufficient to release a gas volume of 3 150 cu. ft. at N.T.P., the total volume enclosed by the screens being approximately 1 200 cu. ft. It will be noted that this concentration is many times greater than that which was found necessary for the indoor tests, dealt with in a later Section.

Even with this concentration, Test No. 23 was unsuccessful, this being in part due to the somewhat prolonged delay in the operation of the automatic release device. The experience does, however, seem to emphasize the risk of failure which may result from dispersal of fire-extinguishing gas in outdoor installations.

It is worthy of note that in Tests Nos. 14, 18, and 19, (approximately 450 cu. ft. at N.T.P.) to cover the volume of 768 cu. ft. already mentioned. This should be compared with the concentration allowed in the indoor test referred to later.

Two tests were carried out with foam, both with fixed nozzles and delayed manual operation. Both these tests were, in general, successful, except that on Test No. 30 certain wads of cotton wool which had been used for firing and had been left in the nest of tubes had to be extinguished by hand. The foam used in Test No. 33 was much thinner than that used in Test No. 30 and the additional quantity of water caused the oil to boil over several times.

Table 4

Type of Risk: Cable Gallery.
Type of Operation: Delayed Manual.
Type of Installation: Portable Hand-Truck.

Test number	Type of medium	Manufacturer's designation	Weather conditions: Wind: Direction	Wind: Speed, m.p.h.	Temperature, °F.	Pressure, millibars	Humidity, %	Time, in minutes and seconds: Burning before start of discharge	Discharge	Quantity of medium discharged	Result of test
7	Methyl bromide	A	NNW.	8–12	52	1 015	55	2.30	– 9	48 lb.	Fire extinguished
16	CO_2	B	WNW.	1–3	66	1 014·6	66	2.30	– 27	100 lb.	Fire extinguished
24	CO_2	C	W.	8–12	63	1 012·8	85	2.15	3.50	100 lb.	Not completely extinguished (see Note)
34	Foam	D	SW'S.	13–18	52	1 006·1	75	2.0	– $20\frac{4}{5}$	135 gal.	Fire extinguished

Notes on Table 4 :—

Test No. 16.—After discharge of 27 sec. bad visibility hindered precise examination. A few doubtful spots of incipient smouldering were noticed and were dealt with by short, sharp puffs.

Test No. 24.—In this test the same quantity of gas was used as in Test No. 16. The diffuser horns used in the two cases were of different design. This may partly account for the difference in effect. The main fire was extinguished just as the supply of gas ran out; in 3 min. 50 sec. smouldering cleats and hessian covering were extinguished with buckets of water. Had any cables been alive this would not have been permissible, though it would not necessarily exclude the use of a hose.

Test No. 34.—Signal for discharge given at 2 min., as fire had reached the desired intensity at that time. It was extinguished in $20\frac{4}{5}$ sec. The foam used was of medium consistency.

the amount of gas released was still greater, being 600 lb. (5 400 cu. ft.) to cover the same volume.

On certain parts of the installation used on Tests Nos. 23 and 27, reliance was placed on small holes drilled in pipes for the release of gas. It was noted that there was considerable delay in the discharge of gas from these holes, apparently due to freezing-up of the holes at the start of the discharge. This emphasizes that at all release points properly designed diffusers should be installed.

Two tests were carried out with methyl bromide—one with fixed nozzles and automatic operation and one with fixed nozzles and delayed manual operation. The second of these tests was not successful, possibly due to the position of the discharge rings not being the most suitable for the purpose.

The amount of gas released on each test was 120 lb.

The question of the consistency of the foam requires very careful consideration. If the foam is too thick it has difficulty in penetrating into odd corners of the installation, whereas if it is too thin it is apt to cause boiling-over of the oil, with additional difficulty in extinguishing. In this respect foam has a different action from water applied under higher pressure.

A further point which has to be watched is the distribution of the foam between the various nozzles of the installation. Unless care is exercised in the layout of the equipment there is a risk of certain nozzles being starved for the benefit of other nozzles.

(b) Back-Up Protection

Four tests were carried out without fixed installations in order to assess the value of back-up protection either from water installations or from foam installations.

Table 5

Type of Risk: Indoor Oil Fire.

Type of Operation: Automatic.

Type of Installation: Fixed Nozzles.

Test number	Type of medium	Manufacturer's designation	Weather conditions					Oil conditions				Time, minutes and seconds		Quantity of medium discharged	Result of test
			Wind		Temperature, °F.	Pressure, millibars	Humidity, %	Gallons		Temperature, °F.		Burning before start of discharge	Discharge		
			Direction	Speed, m.p.h.				Total at start	Lost during test	At start	At finish				
3	Methyl bromide	A	N.N.W.	4–7	52	1 007·8	75	60	20	320	320	2.10	– 9	24 lb.	Fire extinguished (see Note re setting of links)
11	CO_2	B	—	Nil	71	1 014·5	75	60	20	310	285	1.35	1.1	100 lb.	Fire extinguished
20	CO_2	C	W.S.W.	3–5	75	1 012·1	75	60	20	320	335	– 48	1.2	100 lb.	Fire extinguished
37	Water	E	S.W.W.	8–12	60	1 007·9	75	80	80	320	220	– 58	– 9	30 gal.	Fire extinguished

Notes on Table 5 :—

Test No. 3.—It should be particularly noted that the automatic fusible links were set at 450° F. instead of the standard 135° F. used in practice. Also in this case the doors were left open by 1½ in. but the flap was closed.

Test No. 11.—Automatic links set at 135° F., doors and flap closed.

Test No. 20.—Automatic links set at 135° F., doors and flap closed.

Test No. 37.—Automatic links set at 155° F. Doors and ventilating flap open. This test was carried out at the request of the manufacturer.

General Notes.—It was intended to confine this test to inert-gas extinguishers, on the grounds that other forms of extinguishing media were not sensitive to ventilation conditions and that the data obtained from the delayed manual indoor oil fire and the outdoor oil fire could be applied equally well to this indoor risk. One test with water was carried out at a manufacturer's request, but other tests with water and foam were not carried out, for the reasons stated above.

Table 6

Type of Risk: Indoor Oil Fire.
Type of Operation: Delayed Manual.
Type of Installation: Fixed Nozzles.

Test number	Type of medium	Manufacturer's designation	Weather conditions: Wind: Direction	Weather conditions: Wind: Speed, m.p.h.	Weather conditions: Temperature, °F.	Weather conditions: Pressure, millibars	Weather conditions: Humidity, %	Oil conditions: Gallons: Total at start	Oil conditions: Gallons: Lost during test	Oil conditions: Temperature, °F.: At start	Oil conditions: Temperature, °F.: At finish	Time, minutes and seconds: Burning before start of discharge	Time, minutes and seconds: Discharge	Quantity of medium discharged	Result of test
8	Methyl bromide	A	NNW.	8–12	52	1 015	55	60	40	320	—	2.30	?	48 lb.	Fire re-ignited (but see Note as to more severe conditions than other tests in same class of fire risk)
10	Methyl bromide	A	SW.	8–12	67	1 006·4	70	60	20	320	320	2.30	– 25	48 lb.	Fire extinguished
13	CO_2	B	—	Nil	71	1 014·5	75	60	20	300	—	2.30	– 49	100 lb.	Fire extinguished
17	CO_2	B	WNW.	1–3	66	1 014·6	91	60	20	315	300	2.30	1.4	150 lb.	Fire extinguished
25	CO_2	C	W.	8–12	63	1 012·8	85	60	20	320	245	2.30	– 55	100 lb.	Fire extinguished
26	CO_2	C	W.	8–12	63	1 012·8	85	60	20	315	255	2.30	1.55	100 lb.	Fire extinguished
29	Foam	C	SE.	13–18	61	1 005·2	92	55	15	320	160	2.0	1.0	250 gal.	Fire extinguished

Notes on Table 6 :—

Test No. 8.—This was the first test of this series and was made under conditions which were much more severe than the other tests of the series using inert gases. Both doors and flap were left open and under the prevailing wind conditions there was a direct through-draught of 8–12 m.p.h. After discharge the fire was thought to be extinguished, and in fact the main oil fires, both tank and floor, were out; a pocket of burning gas was, however, trapped over the door and flashed back to the tank top, which re-ignited.

Had it not been for an error of judgment in the design of the layout the test would probably have been successful. The layout was subsequently modified and retested (see Test No. 10).

Test No. 10.—Doors closed, flap open.
Test No. 13.—Doors closed, flap open.
Test No. 17.—Doors open, flap closed.
Test No. 25.—Doors open, flap closed.
Test No. 26.—Doors closed, flap open.
Test No. 29.—Doors and flap open.

Table 7

Type of Risk: Outdoor Oil Fire.
Type of Operation: Automatic.
Type of Installation: Fixed Nozzles.

Test number	Type of medium	Manufacturer's designation	Weather conditions: Wind: Direction	Wind: Speed, m.p.h.	Temperature, °F.	Pressure, millibars	Humidity, %	Oil conditions: Gallons: Total at start	Gallons: Lost during test	Temperature, °F.: At start	Temperature, °F.: At finish	Time, minutes and seconds: Burning before start of discharge	Time: Discharge	Quantity of medium discharged	Result of test
5	Methyl bromide	A	NNW.	8–12	49	1 008·8	83	360	60	315	—	1.0	– 30	120 lb.	Fire extinguished
14	CO_2	B	—	Nil	71	1 014·5	75	360	200	320	—	—	—	600 lb.	No fire (see Note)
23	CO_2	C	SW.	6–10	71	1 018·5	65	360	60	315	345	3.38	1.18	350 lb.	Fire not extinguished (see Note)
38	Water	E	SW'W.	8–12	60	1 007·9	75	360	200	320	220	2.49	1.55	900 gal.	Fire not completely exguished (see Note)
42	Water	F	SW'W.	8–12	47	1 015·4	75	360	60	320	260	2.25	1.51	590 gal.	Fire extinguished

Notes on Table 7 :—

Test No. 5.—It should be particularly noted that, at the request of the E.R.A., the automatic links were set at 450° F. instead of the standard 135°–155° F. used in practice. Had this test failed it would have been repeated at 135°–155° F.

Test No. 14.—Almost at the instant of giving the signal to fire, the oil boiled over with almost explosive force. It is thought that this was due to water leaking past one of the control valves and boiling suddenly in contact with the oil. A cloud of finely divided hot-oil vapour was thrown some distance and enveloped several of the operators. The heat of the vapour tripped off the automatic gear set at 135° F. and the gas was discharged. Owing to the explosive nature of the oil and air mixture it was unsafe to fire. The test was abandoned and was repeated later (see tests Nos. 18 and 19, without automatic features). Had either of these tests failed, a further test with automatic gear would have been made.

Test No. 23.—The bottom fire was extinguished and it also appeared that the top oil fire was out. The cables continued to burn and flashed back to the oil, causing the top of the tank to re-ignite. The fire was eventually extinguished with water-spray branch pipes.

It should be noted that only one automatic link was used and, although set at 135° F., remained shielded; it finally operated at 3 min. 38 sec. after the start of the fire. The discharge through part of this installation appeared sluggish. Compare test No. 27, Table 8.

Test No. 38.—The main oil fire was successfully extinguished. One of the cotton-waste firing wads continued to burn slowly; water was left on but failed to extinguish it. It was pressed out by hand.

Test No. 42.—The main oil fire was successfully extinguished in about 7 sec. but one of the firing wads continued to burn; after a total time of discharge of 1 min. 51 sec. the burning wad became extinguished.

Table 8

Type of Risk: Outdoor Oil Fire. Type of Operation: Delayed Manual. Type of Installation: Fixed Nozzles.

Test number	Type of medium	Manufacturer's designation	Weather conditions: Wind: Direction	Weather conditions: Wind: Speed, m.p.h.	Weather conditions: Temperature, °F.	Weather conditions: Pressure, millibars	Weather conditions: Humidity, %	Oil conditions: Gallons: Total at start	Oil conditions: Gallons: Lost during test	Oil conditions: Temperature, °F.: At start	Oil conditions: Temperature, °F.: At finish	Time, minutes and seconds: Burning before start of discharge	Time, minutes and seconds: Discharge	Quantity of medium discharged	Result of test
9	Methyl bromide	A	NW.	8–12	49	1 015	65	360	200	320	—	2.15	1.2	120 lb.	Not completely extinguished (see Note)
18	CO_2	B	—	Nil	66	1 014·6	97	360	40	320	—	4.15	2.12	600 lb.	Fire extinguished
19	CO_2	B	—	Nil	68	1 011·4	75	400	50	325	—	2.30	1.52	550 lb.	Fire extinguished
27	CO_2	C	WNW.	4–7	62	1 012·8	85	360	60	320	—	2.30	2.50	350 lb.	Fire extinguished
30	Foam	C	S.	13–18	60	1 006·1	85	520	80	290	250	3.0	5.40	900 gal.	Not completely extinguished (see Note)
33	Foam	D	WSW.	1–3	44	1 004·4	75	360	240	320	110	3.30	3.2	3 820 gal.	Fire extinguished (but see Note)
39	Water	E	WNW.	13–18	58	1 020·8	55	400	280	320	210	2.40	– 37	300 gal.	Not completely extinguished (see Note)
40	Water	E	SSE.	< 1	59	1 027·9	65	440	340	365	—	1.50	1.10	600 gal.	Not completely extinguished (see Note)
43	Water	F	SSW.	13–18	49	1 012·3	85	400	40	320	250	2.30	$1.51\frac{1}{5}$	360 gal.	Not completely extinguished (see Note)
44	Water	F	S.	19–24	51	996·5	85	400	380	380	—	2.50	– 27	145 gal.	Fire extinguished

Notes on Table 8 :—

Test No. 9.—This installation just failed to extinguish the top fire completely although it successfully extinguished the bottom fire. The former was eventually extinguished by water branch-pipes. Two points are worthy of note. The top protection ring was too low and might have been successful had it been placed from 1 ft. to 1 ft. 6 in. higher; and the wind speed during this test was about twice as great as during any other test using inert gas.

Test No. 18.—Note complete absence of wind.

Test No. 19.—Note complete absence of wind.

Test No. 27.—Note wind conditions; part of this installation appeared to discharge sluggishly.

Test No. 30.—Main fire successfully extinguished but firing wads at two blind spots continued to burn until extinguished by hand. Lack of success should be attributed to installation design rather than to the medium used.

Test No. 33.—Lack of sufficient water pressure in the main caused some delay in foam formation. The foam used, however, appeared very thin; two or three very violent boil-overs occurred during the test, but the fire was eventually extinguished successfully. Some fire outside the dwarf walls was extinguished by means of a foam branch-pipe.

Test No. 39.—Main oil fire extinguished in approximately 10 sec. Part of a firing wad or cable covering was carried in behind the cooling tubes and failed to go out. Water was shut off and discharged again three times, but failed to extinguish this localized fire.

Test No. 40.—This was a specially fierce fire arranged at the request of the manufacturer. The main oil fire was extinguished, but again one of the wads continued to burn although the water was left on. The wad was finally extinguished by hand. Note oil temperature at start of test. In this test the water was turned on earlier than had been intended, owing to an unforeseen incident.

Test No. 43.—This was a fire of normal intensity; the main oil fire was extinguished successfully, but again one of the wads continued to burn and was extinguished by hand. Lack of sufficient water pressure in the main caused some doubt about the result of the test, but it proved unfounded.

Test No. 44.—This was a specially fierce fire, arranged in a similar manner to that produced in Test No. 40, but it became more intense. The fire on the test installation itself was successfully extinguished in 27 sec. The oil, however, had already boiled over before the signal to discharge was given, causing the fire to spread over the ground outside the zone of protection offered by the installation. This outside fire was extinguished partly by water branch-pipes and partly by foam branch-pipes. Note oil temperature at start of test, and increased wind speed.

Table 9

Type of Risk: Outdoor Oil Fire.
Type of Operation: Delayed Manual.
Type of Installation: Fixed with Portable Branch-Pipes.

Test number	Type of medium	Manufacturer's designation	Weather conditions: Wind: Direction	Weather conditions: Wind: Speed, m.p.h.	Weather conditions: Temperature, °F.	Weather conditions: Pressure, millibars	Weather conditions: Humidity, %	Oil conditions: Gallons: Total at start	Oil conditions: Gallons: Lost during test	Oil conditions: Temperature, °F.: At start	Oil conditions: Temperature, °F.: At finish	Time, minutes and seconds: Burning before start of discharge	Time, minutes and seconds: Extinction	Quantity of medium discharged
31	Foam	C	SE./SW.	6–9	60	1 007·1	92	460	85	320	270	4.34	2.25	1 060 gal.
35	Foam	D	SW'S.	13–18	52	1 006·1	75	400	150	365	290	2.30	2.0 + 2.45	3 700 gal.

Notes on Table 9 :—

Test No. 31.—Fire extinguished by one hand-operated branch-pipe using chemical foam.

Test No. 35.—The main fire was thought to be entirely extinguished after 2 minutes' discharge. One small flicker remained inside the tubes; this caused a flash-back after the foam was shut off. Foam was turned on again and successfully extinguished the second fire after discharge of foam for a further 2 min. 45 sec.

Table 10

Type of Risk: Outdoor Oil Fire.
Type of Operation: Delayed Manual.
Type of Installation: Back-Up, Water applied by Fire Engine.

Test number	Type of medium	Weather conditions: Wind: Direction	Weather conditions: Wind: Speed, m.p.h.	Weather conditions: Temperature, °F.	Weather conditions: Pressure, millibars	Weather conditions: Humidity, %	Oil conditions: Gallons: Total at start	Oil conditions: Gallons: Lost during test	Oil conditions: Temperature, °F.: At start	Oil conditions: Temperature, °F.: At finish	Time, minutes and seconds: Burning before start of discharge	Time, minutes and seconds: Extinction	Quantity of medium discharged	Remarks
2	Water (Fire Brigade X)	NE	8–12	50	1 029·4	65	360	60	320	—	4.0	3.31	1 150 gal.	See Note
45	Water (Fire Brigade Y)	NE	32–38	36	1 020·8	85	360	200	380	240	1.50	7.46	2 330 gal.	See Note

Notes on Table 10 :—

Test No. 2.—This was a preliminary test and was carried out without dwarf walls and with no lid on the tank. The oil temperature at start was much lower than in Test No. 45, and the conditions of severity were much less than in any other test.

Test No. 45.—This was a much more severe fire than that produced in Test No. 2. The dwarf walls held the bottom fire under the tank, and the lid, being in position, made the top conditions more difficult to deal with. The initial temperature of the oil was raised to 380° F. at the start, and this, coupled with the very high wind, produced the most severe combination of conditions present at any of the tests. The fire was extinguished mostly by cooling the tank, with a relatively small loss of oil. However, 9 minutes after the fire had been extinguished the remaining oil in the tank boiled over, causing a large loss of oil. The cause of boiling-over was probably due to a certain amount of water falling into the hot oil. Compare this with note on Test No. 14, Table 7.

Two tests were carried out with foam and two with water. These tests were all successful. In one of the tests using foam (see Test No. 35) the fire was thought to be out, but a small flicker of flame remained in the cooling tubes, causing the fire to re-ignite after the foam had been cut off. The second fire was, if anything, more fierce than the first, but was nevertheless successfully extinguished. In regard to the two tests using water, it should be noted that the conditions of test were widely divergent, Test No. 45 being carried out under more severe conditions than Test No. 2, added to which the weather conditions caused increased difficulties.

(c) Indoor Oil Risks (Transformers, etc., in Buildings)

The various forms of fire-fighting media applied to this particular risk were water, CO_2, methyl bromide, and foam.

With one exception (see Test No. 8) all these tests were successful, but it should be pointed out that in the test which was unsuccessful the conditions were much more severe than in the other tests using inert gases. When this test was repeated, however, under the same conditions as those which obtained with others using a similar class of medium, the result was successful (see Test No. 10). In this connection it is interesting to note that the gas-distribution ring was placed too low during Test No. 8 and it is thought that even under the more severe conditions the test might have been successful had the top distribution ring been placed higher. This was actually done for Test No. 10 and the result was successful.

There were in all three tests with methyl bromide, one with fixed nozzles and automatic operation, and two with fixed nozzles and delayed manual operation. There were six tests with CO_2—two with fixed nozzles and automatic operation, and four with fixed nozzles and delayed manual operation, one test with water with fixed nozzles and automatic operation, and one test with foam with fixed nozzles and delayed manual operation.

In Test No. 3 the amount of methyl bromide discharged was 24 lb., sufficient to release a gas volume of 90 cu. ft., the total volume enclosed within the building being approximately 1 200 cu. ft.

In Tests Nos. 8 and 10 the amount of methyl bromide discharged was 48 lb., corresponding to a volume of 180 cu. ft.

In Tests Nos. 11 and 20 the amount of CO_2 discharged was 100 lb., corresponding to a volume of 900 cu. ft. In Tests Nos. 13, 25, and 26, the same quantity of CO_2 was used, whereas in Test No. 17, 150 lb. was used, corresponding to a volume of 1 350 cu. ft. These concentrations should be compared with those which were used for the outdoor oil risk described above.

The concentration of inert gases used should be noted, as inference can be drawn from the figures as to the relative quantities of CO_2 and methyl bromide required to extinguish a fire at a given position. The concentrations used in both cases should serve as a basis for the quantities to be provided for in the protection of installations of this type, where fires may occur presenting the same conditions as were present during the tests. It should be emphasized that during these tests no drop-curtains or other devices were used to prevent leakage of the gas to the outside atmosphere, and should these be provided for in cases where inert-gas protection is chosen due allowance may be made in the minimum quantities of gas to be provided.

In Test No. 37, 30 gallons of water were required to complete extinction, whereas in Test No. 29, 250 gallons of foam were used, although it should be borne in mind that water was applied by the operation of the automatic discharge heads after the fire had been burning for 58 sec., whereas the foam was used to extinguish a fire which had been burning for 2 min.

From these tests it would appear that relatively small quantities of water are required for installations where the amount of oil involved is small. In regard to foam, the installation used for this test appeared to be well balanced, delivering a foam of a medium thick consistency, in which there was no apparent waste of medium before the fire was successfully extinguished.

As in the case of outdoor fire risks, special consideration must be given to the layout of the various components of the installation, whether it be for gas, foam, or water, and careful balancing is desirable in order to ensure either correct concentration of gases or correct distribution of foam and water.

(d) Cable Tunnel (Enclosed)

In this series of tests only methyl bromide and CO_2 were used as fire-fighting media. Water and foam were not used in this case, as they were used in connection with the tests in the cable gallery, and it was considered that the data obtained in this manner were sufficient to enable the tests of these media in the tunnel to be dispensed with.

With one exception (see Test No. 22) all these tests were successful. All the fires in this series were surprisingly fierce, considering the short time-interval during which the cables were alight before the application of the fire-fighting medium. In all, there were two tests with methyl bromide, one with fixed nozzles and automatic operation, and one with fixed nozzles and delayed manual operation. There were four tests with CO_2, two with fixed nozzles and automatic operation and two with fixed nozzles and delayed manual operation.

In Test No. 4 methyl bromide was installed for test and the automatic operating gear was of the British Electricon type. This type of detector proved to be so sensitive that it was found impossible to light the fire without tripping the operating signal. Under these circumstances it was decided to abandon the test as an automatic test and to repeat it without any automatic device. This non-automatic test was quite successful, and as in this case the fire burned for 2 min. 45 sec. before the methyl bromide was discharged it was considered that the same medium would have been equally successful had it been operated by automatic gear.

The amount of methyl bromide used was 24 lb., corresponding to a volume of 90 cu. ft., whereas the total cubic content of the tunnel was approximately 1 100 cu. ft.

In all the tests in which CO_2 was used a total quantity of 100 lb. per test was installed. This corresponds to a volume of 900 cu. ft. In both automatic tests CO_2 was

successful, whereas in the non-automatic tests CO_2 failed on one occasion (see Test No. 22). In the latter case failure was due to smouldering materials, and it should be noted that there was a considerable difference in the time of discharge of the gas between the successful test and the unsuccessful test, from which it would appear that rapid discharge is an essential element of success.

(e) Cable Galleries (Exposed to the Atmosphere)

In the cable gallery, water, foam, methyl bromide, and CO_2, were tested. In all eight tests were carried out, six of which were successful and two unsuccessful. In this case no automatic installations were tested, as it was thought the data obtained from the delayed manual test were sufficient. Four tests were carried out with fixed nozzles and delayed manual operation, and four tests by means of portable hand apparatus.

One test was carried out with methyl bromide supplied by a portable hand truck, the quantity of medium discharged being 48 lb. Three tests were carried out with foam, of which two were supplied by fixed installations and the third by a portable operator of the knapsack type. In the fixed-installation tests one test was successful, using 260 gallons of foam, whereas the other test was unsuccessful although 800 gallons of foam were discharged. The foam that was used successfully was of a thin, watery consistency, whereas the foam which was unsuccessful was of a thick consistency which prevented it from running freely into the space between the cables and the wall. Water was used in two fixed installations of different types; in the one case the fire was extinguished successfully with 94 gallons of water, whereas in the other case it was extinguished with 13 gallons of water. Two tests were carried out with CO_2 by means of a portable hand truck. In both cases 100 lb. of CO_2 was discharged. One test was successful and the other was unsuccessful, the lack of success being due to smouldering material. One test only was carried out with a portable foam installation, using foam of a thin consistency. This test was successful, and the quantity of foam used was 135 gallons.

(11) REMARKS

(a) General

The above conclusions apply to the tests carried out under the conditions obtaining on the various testing installations and at the time of the tests. The conclusions apply to the fire-fighting aspect alone and do not attempt to take into consideration any aspects of risk of damage to electrical plant or the possibility of shutdowns due to temporary breakdown of insulation caused by any of the extinguishing agents used. Considerations of this nature are entirely dependent upon local conditions covering a wide range of factors, and upon this point each case should be considered on its merits.

Whatever type of installation be provided, whether fixed or portable, automatic or hand-operated, it is essential that adequate provision should be made for isolating electrical equipment affected by the fire as quickly as possible, and for hydrants, so that in case of emergency or any unforeseen incident an efficient back-up protection is available for immediate use if required.

(b) Installations

(i) *Water*

Where water is used in the form of fixed installations it is essential that an adequate supply of water be available at all times. Storage tanks, when used, should be of sufficient capacity to provide a margin of safety, and in view of the time taken to extinguish free-burning materials during the tests it is suggested that it should be equivalent to 4 to 5 minutes' supply. Where mains are used they should be of sufficient bore to prevent excessive pressure-drop between static and flowing conditions and should not be subject to large variations of pressure due to supplies being drawn elsewhere. Where automatic installations of the dry detector type are used in residential areas, adequate air storage should be provided in order to avoid complaints due to the noise during night hours of frequent starting and stopping of the compressor.

In no case should the running pressure fall below 50 lb. per sq. in. at the highest nozzle when all the nozzles are open.

The layout of the nozzles should be such that the risk is well covered at all points, and particular attention should be paid to blind spots where combustible materials such as rags, cotton waste, paper, or cardboard, may be inadvertently placed or may gather.

(ii) *Foam*

Fixed installations of foam appliances must be carefully balanced in order to ensure that the foam supply is evenly distributed over the whole risk. This balance appears more critical than that for water, and unless precautions are taken one part of the installation may rob another of an adequate supply, thereby reducing the effectiveness of the installation as a whole.

The consistency of the foam should not be so thick that it flows over oil with difficulty, or that it will not creep into inaccessible places. On the other hand, for oil risks in particular, it should not be so watery as to cause undue "boil over." In outdoor installations, especially in exposed places, precautions should be taken to ensure that the installation is so designed that the likelihood of foam being carried away from the risk by a possible high wind is reduced to a minimum.

(iii) *Gases*

Gas installations require careful design, and it is probably true to say that the success of this type of protection depends as much upon the installation itself as upon the medium used, if not even more so. During the tests carried out, methyl bromide was found to be quicker in action than CO_2. Owing to this fact it is authoritatively stated* that there is no more risk to the health of the operator with methyl bromide than with CO_2 alone, and it is held that the medium which extinguishes the fire in the shortest time offers the least risk of injury to personnel.

(c) Automatic Features

Automatic operation may be made to depend upon detector heads of various types actuated by a rise of

* London County Council, Annual Report 1937. Public Health Report for the year 1937 of the County Medical Officer of Health, pp. 74–75.

temperature. Complete reliance upon a single detector should not be tolerated, as this may cause considerable delay in operation for several reasons. A reasonable number of detectors should be provided for every risk, and should be installed at strategic points.

(d) Smoke Detection

Smoke detectors were used on one test and proved so fast in operation that it was found impossible to ignite a fire without bringing the detector into action. There are many situations in electrical installations where smoke detection could be given consideration with advantage.

(e) Dwarf Walls

The dwarf walls used in the testing installation were too small and too close to the base of the installation to prevent flow of burning oil. In practice, dwarf walls should be such that burning oil issuing from a transformer or a switch would fall inside these walls. The pits formed by such walls should be provided with adequate drainage designed to prevent the flames from an accumulation of burning oil from acting upon the remainder of the installation, and also to avoid a possible overflow of burning oil with the consequential danger of fire spreading.

(12) GENERAL RECOMMENDATIONS

A. Fixed Installations

(a) Outdoor Oil Risks (Transformer Banks, etc., Exposed to the Atmosphere)

For this type of risk the most suitable form of fixed installation is the atomized-water type, or, if local conditions are such that this type cannot be easily employed then foam can be used.

If neither of these types can be utilized, inert-gas installations can be used, provided that suitable barriers and screens are installed to prevent dispersion of gas due to atmospheric conditions and that a sufficiently large quantity of gas is provided. Where other forms of media are available gas protection is not recommended for this type of risk.

(b) Indoor Oil Risks (Transformers, etc., in Buildings)

Where weatherproof metal-clad gear is installed atomized water will provide adequate protection, subject to precautions being taken to ensure that any apparatus not of the weatherproof type is not liable to suffer water damage which may have serious consequences.

Where conditions are such that reasonable protection from draughts is provided, gas protection is adequate and has the advantage of leaving no trace and of being immune from risk of damage to other apparatus.

Adequate protection can be obtained with foam installations; these, however, have the disadvantage of leaving deposits which may hinder repair operations.

(c) Cable Tunnels (Enclosed)

For cables in enclosed spaces not liable to draughts, inert-gas protection is effective under conditions of rapid operation. Delay in operation may result in sufficient evolution of heat to cause smouldering, with attendant risk of re-ignition.

Water and foam are subject to the same limitations and applications as relate to indoor oil risks, but in the case of tunnels drainage and cleaning problems may give rise to greater difficulties.

(d) Cable Galleries (Exposed to the Atmosphere)

If there is no danger of brisk through-ventilation, and provided care is taken to supply gas in sufficient quantity to counteract dispersion, the remarks made above in connection with cable tunnels apply to cable galleries.

Where brisk through-ventilation may occur and cannot be automatically checked, gas protection cannot be relied upon as the only line of defence, and unless chosen by weight of other considerations should not be used.

In such cases water or foam installations will afford adequate protection.

B. Portable Appliances

The most suitable type of medium for portable appliances follows the same general lines as the most suitable medium for fixed installations. It should, however, be borne in mind that, on account of the conductivity of the medium, foam and soda-acid should never be used on live apparatus owing to the danger to the operators. Portable appliances should always be of adequate capacity for the risk they are intended to cover.

During the course of the tests no opportunity arose for using carbon-tetrachloride extinguishers. Numbers of small portable extinguishers of this type are in use and have proved successful in dealing with small incipient fires.

Great care should be taken in using carbon-tetrachloride, carbon-dioxide, or methyl-bromide extinguishers in confined spaces, on account of risk to the health of the operator. When such extinguishers have been used in any closed space thorough ventilation is necessary before the room is re-entered.

C. Back-up Protection

Whatever type of installation is installed, whether fixed or portable, back-up water-hydrant protection should be provided in case of emergency. The position, number, and layout, of such hydrants should be considered for each case on its merits after consultation with the chief officer of the local fire brigade where this is possible.

ACKNOWLEDGMENTS

The Association acknowledges, with thanks, the cooperation throughout the tests of the County of London Electric Supply Co., Ltd., who placed at its disposal facilities which made tests on this scale possible. Thanks are also due to the various manufacturers of fire-fighting equipment who took part in the tests and to the various fire brigades who also assisted.

DISCUSSION ON
"SAFEGUARDS AGAINST INTERRUPTIONS OF SUPPLY"*
NORTH-WESTERN CENTRE, AT MANCHESTER, 29TH MARCH, 1938

Mr. W. Kidd: The amount of expenditure on safeguards which can be justified is dependent on circumstances; public feeling demands that places where large numbers of people congregate, and certain services, should have a higher degree of security than others. When considering this subject we should be careful to get the correct perspective, and this can only be done by collecting statistics of the causes of interruptions.

The large supply system in this area relies chiefly on underground cables and has only a few miles of overhead lines, with two or three outdoor switch equipments. It is our practice to tabulate the causes of failure of high-voltage supply, however small, for 3-year periods (the next being due next year). The last results were as follows: Switchgear faults (3 per annum), 23 %; inadvertent operation of relays, 33 %; cable faults, 44 %. The system has about 800 circuit-breakers. The principal causes of switchgear failures have been the 33-kV bushings in the earliest designs of that type of gear, and water getting on to gear in the older consumers' substations. The original bushings have all been replaced by others of modern design. Oil circuit-breakers have not been the weakest link, and fire is certainly not the greatest trouble, but I certainly advocate taking adequate precautions to deal with fire.

I agree with the authors that protective gear is essential and that it should be of a type which will cut out the faulty section only. Some 15 years ago we specified busbar protective gear for 33-kV substations, balancing the current transformers on incoming and outgoing circuits; and using the transformers also for other purposes. The scheme was not a success. It has since been modified, and we now have a system which is reasonably satisfactory. One of the lessons which has been learnt is that transformers for protective gear should not be used for any other purpose. We have not sufficient faith in any existing scheme to use it for the busbars in large generating stations, but we should like to have the opportunity of considering any suggestions of the authors on this subject.

Supply systems should be sectionalized to limit the area affected by any failure and (a particularly important point as regards densely-loaded systems) to limit the fault current to a quantity which can be dealt with by switchgear of reasonable cost. Each area and each substation should have two sources of supply.

Do the authors consider that pneumatically-operated circuit-breakers are better and more reliable than solenoid-operated gear?

Cable sections should be selected so as to suit the possible fault conditions. I have met instances where the cores have disappeared during a fault. Fig. 2 should be used with discretion, otherwise cables larger than necessary will be selected.

Fig. 5 represents a bad arrangement; there should be two circuit-breakers on cable busbars between important sections of switchgear.

All earth-connections should be of adequate section to take the possible current for a suitable period. This is a matter which, I am afraid, is often not given much thought. A large generating station should have duplicate earthing resistances.

We shall always be liable to have faults of some sort on our systems, and a point which the authors do not deal with is the reduction of the period of interruption.

Owing to the greater use of alternating current the tendency is to increase the number of unattended substations. A large percentage of the period of interruption is taken up in ascertaining what has happened and where, and in getting to the substation. I strongly advocate the adoption of supervisory equipment, which gives us an eye with which to see into distant substations and an arm for operating the gear. Experience has proved it to be a valuable adjunct for system control. Indication of why a breaker has opened, i.e. on account of overcurrent or earth leakage, can be given, and equipment has recently been developed whereby a large number of substations can be dealt with from one control board common to them all, thus considerably reducing the cost of an installation and making large-scale supervisory control physically and commercially possible.

Mr. H. Pearce: With much in this paper I am in complete agreement, although I do not always reach the same conclusions as the authors. When an engineer is dealing with physical factors which may be varied one at a time he knows (after he has performed a certain number of experiments) the results to be obtained from a given action. In practice he usually has to deal with circumstances involving a large number of variables, however, and some of the laws governing the variables may be known, some guessed at, and others entirely unknown; it is then far more difficult to arrive at a correct and wise decision, and therefore not surprising that the views of engineers differ widely in some matters. I think I can best illustrate this by touching on the experience of testing circuit-breakers to destruction. At a certain point in such a test there is a failure, and we say "Yes, obviously that part must be made stronger"; and we make it stronger—either electrically or mechanically. We repeat the test, to find that something else is not yet strong enough; and if we carry the research further we may find that we can repeat the process again and again, because the real cause of the trouble has not been corrected.

* Paper by Messrs. H. W. Clothier, B. H. Leeson, and H. Leyburn (see vol. 82, p. 445).

For example, take the diagram shown in Fig. 3. As it is impossible for the authors to show all kinds of layout one can assume they regard this as the best example of a large switchgear installation of its type, whereas I would suggest that the diagrammatic arrangement (quite apart from the constructional details) is less satisfactory than the more usual duplicate-busbar system to which they also refer.

Another example is the question of fire prevention. A man who has had a serious fire obviously must set out to guard against fire, but I am sure the authors will agree that it is necessary for him to go much further and ascertain the actual cause. They rightly say that the first thing to do is to make sure that the insulation is of the right quality, and secondly, that it is looked after and tested regularly. If in addition the protective gear will isolate instantaneously every fault in the station, there will be little need for the ultimate safeguard of fire-fighting equipment.

Mr. O. Howarth: We are concerned with safeguarding both against interruptions of supply and against interruptions of industrial processes. Interruptions of the latter type may occur without any interruption of supply. Faults involving a reduction of the voltage to zero or thereabouts for a second or two may cause serious interruption to industrial processes without interruption of supply. In this connection it seems necessary to have, as one precaution, time-lags on no-volt releases which are fitted to industrial-motor control units. Again, if the voltage is low for a second or two and then recovers, the motors are liable to trip out on overload. Speedy clearance of faults is essential if these troubles are to be avoided.

I have noticed that grid faults do not cause much disturbance to the supply undertakings in this district so far as the interrupting of processes is concerned. This, I think, is due to the fact that between the fault and the generating station there is a considerable amount of impedance, and grid faults do not reduce the voltage to anything like zero on the high-voltage distribution systems of the local undertakings; so that a longer time can fortunately be afforded for grid faults than for faults on the high-voltage distribution systems.

The necessity for quick clearance of faults is stressed by the authors, and in this connection I think it is unfortunate that more attention has not been paid to the protection of transformer banks. On page 457 (vol. 82) the authors say "A typical exception is the protection of a power transformer with on-load tap-changing . . ." etc. A straight balanced system cannot be used. The earth-leakage system gives a very restricted degree of protection, as it will only clear on earth faults: phase faults within the protected zone have to be dealt with by the overload protection, with the result that such faults cause considerable disturbance. Satisfactory protection for transformer banks would be obtained if a current transformer were put at each end of each winding and a relay connected to take the spill current in the usual manner. This would take account of tap-changing, and would give full protection against phase faults, but not of course against short-circuited turns. In my view, the slight additional cost involved would be worth while.

Mr. T. W. Ross: There are two points in the paper which I wish to discuss, namely (*a*) rapid reclosure of circuit-breakers and (*b*) arc-suppression devices.

The paper gives the impression that it is possible to clear transient faults on interconnectors by high-speed circuit-breakers and then to maintain or restore synchronism between the plants coupled through the interconnector by rapid reclosure of the circuit-breakers. I doubt whether such a scheme is feasible where the faulty interconnector forms the only tie between two large power stations. The very fact that the interconnector is carrying load means that its severance will bring about a relative change of speed between the stations, irrespective of any phase displacement which the short-circuit may have produced, so that when the circuit-breakers reclose a very heavy current will flow over the interconnector in an attempt to restore synchronism. Whilst it is possible that, under favourable conditions, the stations may again pull into step, considerable surging will take place and under less favourable conditions synchronism may not be restored. There is also the possibility that the inertia of the machine load would make conditions more onerous. If, however, more than one tie exists the severance of an interconnector will only increase the impedance between the stations, and in such cases it is possible that rapid reclosure of the circuit-breakers would be beneficial in preventing loss of synchronism. This is the condition which is usually met with in practice, and high-speed circuit-breakers with rapid reclosure may form a satisfactory method of maintaining continuity of supply following line short-circuits.

The scheme put forward by the authors as an alternative to the arc-suppression (Petersen) coil is ingenious but it does not appear to possess any advantage over the simple coil, which has been in use for many years and is gaining adherents very rapidly throughout the world. I should like to ask the authors whether they know of any cases in which operating difficulties can be directly attributed to the coil. I do not agree with them that high-speed rapid-reclosing circuit-breakers are preferable to arc-suppression coils on networks above 100 kV. It is true that the coils prevent the use of graded insulation on power transformers, and for this reason cannot be used on the 132-kV grid lines in this country; but they are in successful use on other 132-kV lines here and on many systems in Europe and America where the voltage is as high as 220 kV.

Dr. J. L. Miller: I agree that a power-factor test is not always satisfactory in determining the quality of insulation unless the deteriorated part of the insulation it is attempting to detect forms a reasonably high percentage of the total insulation. We have found with bushings, however, that the test is satisfactory, and our experience with bushings which by mischance have not had correct treatment during manufacture is such that (1) the power-factor/voltage or loss-factor/voltage curve deviates considerably from our standard; and (2) the pressure test often causes a deviation of this curve from the curve obtained before the pressure test. The conclusions to be drawn are that insulation must be proved in the factory and that any fault in manufacture can be readily detected. Experience on all types of insulation has also shown us that often damage is done by too high a pressure test, and thus I can say that generally I am in

agreement with the authors' views on this aspect of high-voltage insulation testing.

On page 465 (vol. 82) the authors state that to obtain the required co-ordination of insulation it is necessary to install station apparatus of a size corresponding to a higher voltage-rating than the actual service voltage. The phraseology of this statement is indefinite and may give an erroneous impression. Insulation co-ordination is not simply the putting-in of equipment having a voltage rating higher than normal; it is a much more complicated business, and involves a study of the breakdown-voltage/time characteristics of the various sections of insulation for small intervals of time to breakdown. Even when such co-ordination is carried out to the fullest extent it does not work very well, owing to the differing characteristics of various kinds of insulation. For instance, a particular line insulator having the same breakdown voltage with a time to breakdown of a few microseconds as the insulation in a particular transformer, would, with a time to breakdown of 0·5 microsecond, say, have a breakdown voltage perhaps 3 times as great. Thus no real protection under steep-wave-front or direct-stroke conditions would be afforded here if co-ordination were carried out for slow-fronted conditions.

This leads me to the consideration of the authors' protective gap. It is well known that the rod-gap exhibits a high impulse ratio under rapidly-rising voltage conditions, and as an alternative the sphere-gap has frequently been suggested. The disadvantages of the sphere-gap appear to be that (1) it is cumbersome, and for high-voltage circuits takes up a great deal of space; (2) it requires screening; (3) like any other gap, it requires a low earth resistance; (4) its wet-flashover value at low frequencies is low, so that either it requires a housing or its setting must be large enough to prevent switching surges flashing-over, with the consequence that lightning impulses are not so limited in amplitude as they might be; (5) its surfaces might be seriously damaged by the power-frequency follow-up current, so that its flashover characteristics would be altered; and (6) even spheres have an impulse ratio with very rapid rates of voltage-rise such as exist when they receive a direct lightning hit.

The difficulties outlined in (5) and (6) are very real; so are the others, when gaps of a size suitable for lines operating at 66 kV, say, or above are required. I would therefore ask the authors how far the difficulties I have enumerated are overcome by the use of their design of protective gap. Figures relating to its impulse breakdown characteristics under rapidly-rising voltage conditions would be welcomed by all interested in transmission engineering.

Finally, I would discuss the remarks made on page 465 which refer to protective cables and surge absorbers. The cable produces a flattening effect by virtue of the to-and-fro reflections between its two ends. The output voltage wave therefore consists of a series of staggered steps each of which will, unless the cable is very long so as to ensure adequate attenuation, be steep. The surge-absorber output wave is smoothly rounded, so that for equal effective wave-front durations the cable does not reduce axial gradients in transformer windings to the same extent as the surge absorber. Again, if there is a flashover near the line-cable junction, the steep collapse of voltage there is a little later impressed on the transformer without any stepping, and in fact matters are made still worse by the return of opposite-polarity reflections. This phenomenon does not occur with the surge absorber, so that unless a cable is very long it is quite ineffective under such conditions compared with a surge absorber. Under direct-stroke conditions the voltage impressed at the line end of a cable or a surge absorber will be much greater than the normal line impulse flashover voltage. Thus both have to be insulated to cater for this. Obviously it is less expensive to provide adequate insulation in a piece of apparatus which is of small size than to employ several hundred yards of grossly over-insulated cable. Additionally, if the generally accepted assumption that the surge voltage due to a direct stroke is of short duration is correct, the surge absorber will give something of the order of a sixfold reduction in voltage at the protected transformer, while the cable will rely on attenuation to give its reduction. Obviously the cable would have to be very long indeed to give a similar reduction. Thus for transformer protection no case can be made for preferring a cable to a surge absorber, although where long cables have to be used in cities for reasons of public safety they certainly afford some surge protection. The authors could hardly be expected to be aware of all the facts I have dealt with on the subject of surge protection, since little information on the surge characteristics of surge absorbers has been published; particularly in regard to flashover and direct-stroke conditions. The subject is, however, being dealt with in considerable detail in a paper to be read before the Transmission Section.

Mr. S. R. Mellonie: With regard to Fig. 3, I would ask the authors why two earths are provided on short sections of the busbars while the main busbars are apparently left without an earth-connection.

I am in agreement with their suggestion that the power-factor test on insulation should be a routine test. Recently tests carried out on bakelized-paper-insulated bushings 12 to 14 years old showed that most of them were satisfactory, though one or two had to be replaced.

On page 455 (vol. 82) the authors deal with developments in high-speed relays; the abnormal relationship between voltage and current that must exist during the asymmetrical period appears to set a limit to the speed of relays. Hence relays embodying a directional feature need not be designed to operate in less than 2 cycles.

Have the authors any operating experience of the relay shown in Fig. 4A?

The paper describes several schemes for busbar-zone protection, which is now receiving more attention. These schemes require a relatively large number of relays—no less than 6 were necessary for a simple installation to protect two sections of a metalclad board. The tests made on this installation, which included a busbar-sectionalizing switch, gave very satisfactory results.

(*Communicated*) The authors do not mention a very simple form of busbar protection which can be applied to existing cubicle gear to give some measure of security. If the neutral oil circuit-breaker is made automatic and provided with a time-element relay to ensure that all feeder breakers will clear first, then in the event of a single-phase busbar fault the neutral switch will trip and interrupt the fault current, which is of course limited by

the neutral resistance in most cases. The only disadvantage is loss of the earth neutral for a few minutes. Such a scheme has been in operation for some years, and on two occasions has justified its introduction.

Mr. A. J. Nicholas: I feel that more emphasis should have been given in the paper to the problem of the layout of switchgear. This problem has been dealt with in stages. In many undertakings the C.E.B. connection was made at the generator busbar and in practically all cases there was one vital point in the system where all the power was fed in and out, and if anything went wrong the whole system was affected. A step in the direction of sectionalization was made when separate sections of switchgear were separated by walls and were even placed in separate switch-houses, but the major problem remained in that the complete switchgear installation was located at one site. To-day we are confronted with the major problem of air raid precautions, and it appears necessary that we should have more than one ingress point into the supply system, so that in the event of a total failure of one supply, another supply would be available geographically separated from the faulty connection.

Mr. C. Ryder: I am rather interested in the design of the directional relay shown in Fig. 6, and in the statement "High-speed operation of protective systems is easily obtained with non-directional current-operated relays, but has hitherto been difficult to obtain with directional relays." I should like to know what prompted the authors to make that statement, and whether it is the result of service experience or of tests. If it is the result of tests, what kind of relays were involved, and to what extent did the results lead the authors to design their new type of directional relay? Directional relays of the induction type can be made to operate in times of 1 cycle or less, and such relays are in service. They do not seem to be affected by the transient conditions referred to in the paper, and because of which the operating time of the relay of Fig. 6 has to be deliberately increased to 1–1½ cycles. I should like to know whether this arrangement measures watts, and therefore gives a true indication of the power direction. Two coils, labelled I_1 and I_2, are shown, and I am rather in doubt whether one is supposed to be a voltage coil or whether they are both current coils. If this relay in fact makes a watt measurement, it would also be interesting to know for what range of power factor and values of current and voltage (particularly under low-voltage conditions) the relay maintains a true indication of the direction of power.

The Interlock system shown in Fig. 9 gives the impression of having a large stability margin. On the other hand, when we consider that the margin is only 1·5 cycles, i.e. 0·03 sec., the question immediately arises whether a theoretical margin of this nature, within which time certain operations should have taken place, has as much practical value as the diagram would seem to indicate. Methods dependent upon small time-margins for discrimination are in general to be deprecated; perhaps the authors would amplify their scheme a little more and explain how the "race" between stability and instability is avoided.

Mr. H. A. Lamb: The principal criteria on which schemes for busbar-zone protection should be judged are, as the authors stipulate, firstly freedom from unwanted tripping, and secondly certain and rapid operation under internal fault conditions. But it would seem that simplicity is also a criterion provided this is attained without sacrificing the former two. In the scheme shown in one of the authors' slides an average of 2 relays were used per primary circuit connected to the busbars protected: another form of busbar protection is available wherein two independent means of fault detection are employed to obviate unwanted electrical operation, but the relays used are so designed that the two means of fault indication are co-ordinated within them, and hence a reduction in the complexity of the equipment is obtained. As one relay is used to control the circuit-breaker of each primary circuit, no multi-point tripping relays are required. A diagram illustrating this scheme is shown in Fig. H, from which it can be seen that a "balanced" leakage system secures discrimination, whilst stability on through fault is ensured by the leakage-to-frame system. In a particular relay the windings connected to both systems must be simultaneously energized to cause operation; the relays are the double-wound induction type, of the Translay pattern. Where the busbars are multiple, small-wiring integrity is constantly checked by a simple alarm relay.

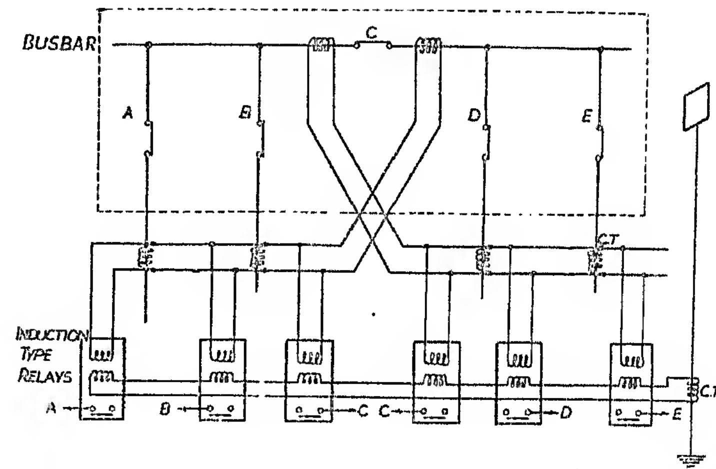


Fig. H.—Instantaneous discriminating busbar-zone protection using induction-type relays of Translay pattern.

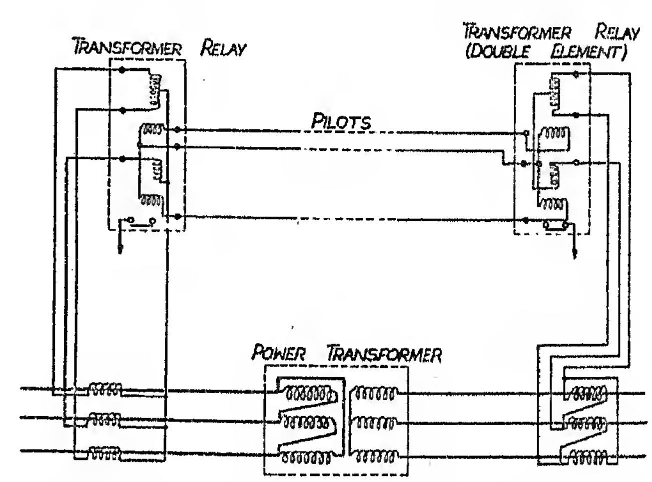


Fig. J.—Unit protection for power transformer having on-load tap-change equipment, using induction-type relays of Translay pattern.

Reference has been made both by the authors and by Mr. Howarth to the difficulty of protecting power transformers having on-load tap-changing equipment by

means other than simple overload and restricted earth-leakage protection. The type of relay named above has, however, been adapted to provide a unit protective system of the balanced class which meets this case (see Fig. J). Currents proportional to the line currents are summated in relays associated with the primary and secondary sides of the power transformer; the summations are arranged to produce resultant voltages which are opposed through interconnecting pilots, in series with which are the complementary operating coils of the induction relays.

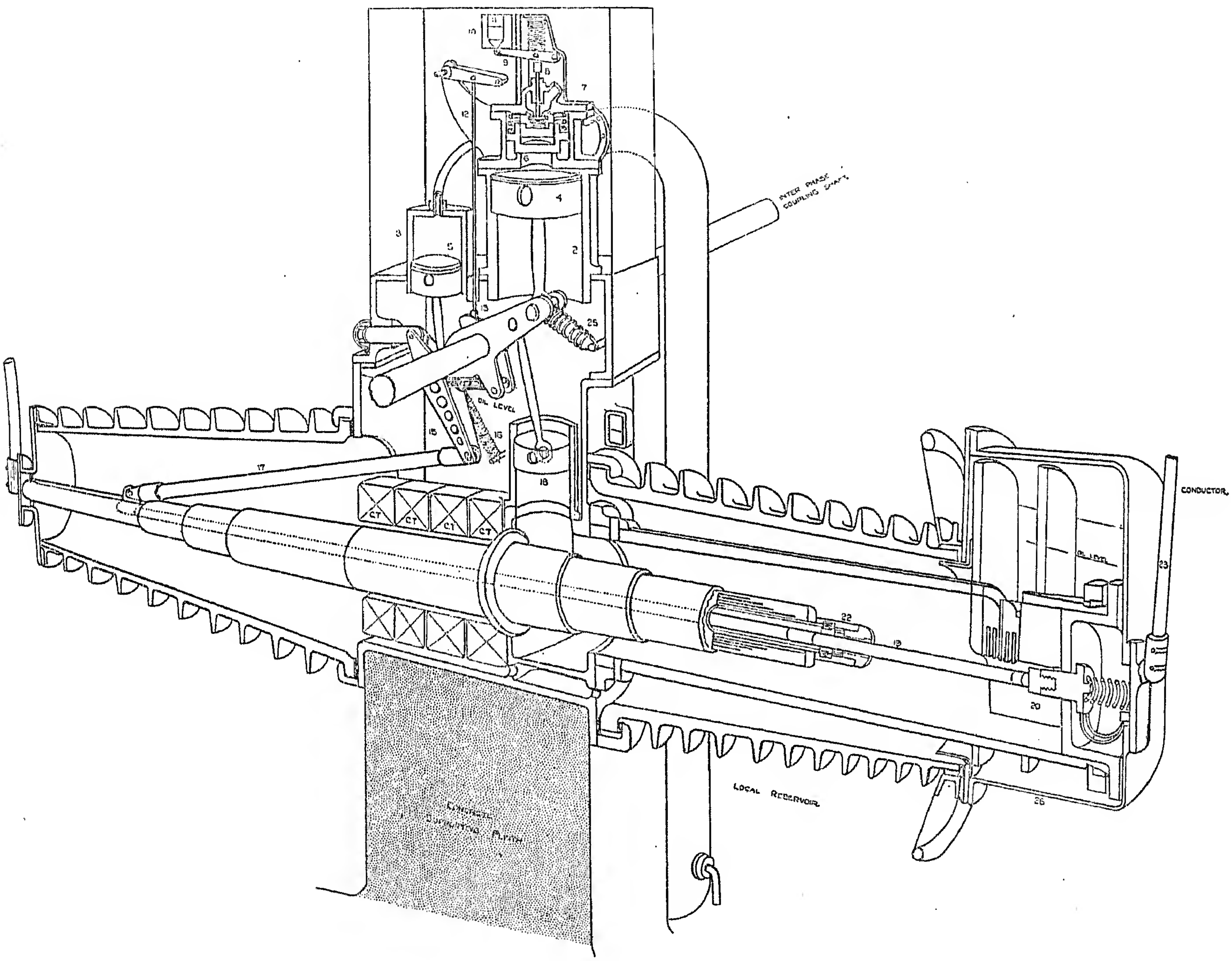


Fig. K

In the event of an internal fault, current circulates in the pilot system and produces a tripping torque. By adjustment of the magnetic and time/current characteristics of the relay elements, and the use of an inductive bias, the system is rendered stable during switching current-surges and through faults, independently of ratio-changes of the main transformer within normal tap-change limits.

Mr. C. H. Flurscheim: I shall confine my remarks to the authors' high-speed 132-kV circuit-breaker. This has an outstanding performance for a circuit-breaker employing interrupting contacts of the self-energized type. It would appear that the arc duration has been reduced by as much as 50 % as compared with the normal contact construction, by means of increasing the opening speed. I should like to ask the authors what total arc-lengths are associated with the tests given, and also what are the durations and arc-lengths to be expected when charging currents of long lines are interrupted. Oil deterioration is a function not only of arc duration but of arc length, and it seems to me this factor should be taken into account when breaker performances are under consideration, although of course it has no effect on the overall clearing-times tabulated.

The authors claim a 40 % oil reduction due to the use of their rotating contact assembly. The oil volume would appear, however, to be about 800 gallons per phase, which is of the same order as that required for the more usual type of vertical double-break construction.

During the past few years I have been associated with the development of high-speed breakers which are closed and opened by compressed air, but in these designs it is preferred to use the external energy available in the compressed air for performing the actual work of interruption, by forcing the oil across the arc mechanically. With this arrangement the performance becomes entirely independent of current and practically independent of

voltage within the breaker rating, the maximum 3-phase arc-durations and total arc-lengths for 132-kV service being about $1\frac{1}{2}$ cycles and 6 in. respectively. The type of construction employed has enabled the total quantity of oil to be reduced to 200 gallons per phase, or less than one-quarter of the normal amount, while the bushing current-transformer incorporated in the oil-tank design has been retained. The arrangement of the bushing mechanism and interruption contacts is shown in Fig. K, while a typical series of test-results is given in Fig. L. Contact separation is obtained in 0·03 sec. from receipt of the trip impulse.

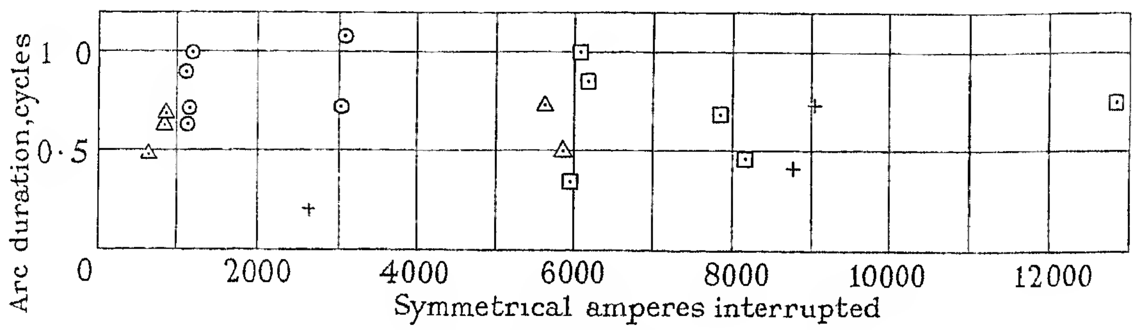


Fig. L.—Single-phase recovery voltages for impulse circuit-breaker.

⊡ 35–50 kV. + 51–75 kV. △ 76–100 kV. ⊙ 101–125 kV.

Mr. S. Farrer: I should like to express agreement in general with the useful perspective given by the authors on methods and equipments for reducing system disturbances under emergency fault conditions to a minimum. In some cases, however, considerable complication has been introduced in order to obtain the maximum amount of flexibility. The use of the pneumo-oil system of operation for the circuit-breaker described on page 470 (vol. 82) is certainly ingenious but appears to have several inherent difficulties. Perhaps the authors would indicate whether the only means of holding the moving contact in position is the pressure of the oil itself. If this is the case, the possibility of leakage in the oil system is very serious. Also, is it possible to provide a positive indication of the open and closed positions of this circuit-breaker? I should like to know what means are adopted by the authors to provide for expansion due to heating of the oil in the system in such a way that the oil is not continuously under pressure when the circuit-breaker is not operating.

Undoubtedly the breaking performance given in Table 3 for the authors' high-speed 132-kV breaker is good, but I think that even an impulse type of oil circuit-breaker can be simpler and yet provide equally short arcing times. Fig. M shows one phase of a breaker which, on being tripped, is opened by compressed air, which also acts on a piston (top right-hand corner) coupled directly to a second piston below oil level. The latter forces clean oil at a definite velocity directly across the parting contacts, which are fitted with suitable shrouds. Operated with a single break on 66 kV, a breaker of this type has cleared currents corresponding to 1·5 million kVA in 1–$1\frac{1}{2}$ cycles of arcing, whereas at lighter currents the arcing time can be less than $\frac{1}{2}$ cycle. Without the impulse characteristic, however, a similar form of single-break self-blast circuit-breaker can interrupt currents corresponding to 1·5 million kVA in $1\frac{1}{2}$ cycles, but with periods of 2–3 cycles of arcing for the lighter currents.

Referring to the question of over-voltage protection, one method is to use arc-suppression coils and parallel spark-gaps, as demonstrated by the authors, or, alternatively, to use automatically-reclosing circuit-breakers. A more direct method would be to use a simple form of oil circuit-breaker in series with a high-speed spill-over gap near to the substation, as shown in Fig. N. The circuit-breaker consists merely of a floating plunger having a butt contact at its upper end and a soft iron sleeve at its lower end. When over-voltages cause flashover of the protective gap the follow-up power current flows through the coil, thereby opening the moving contact against the action of a spring which normally keeps it closed. The power current is interrupted in the cross-jet explosion pot, causing the coil to become de-energized, and then allows the plunger automatically to resume its original

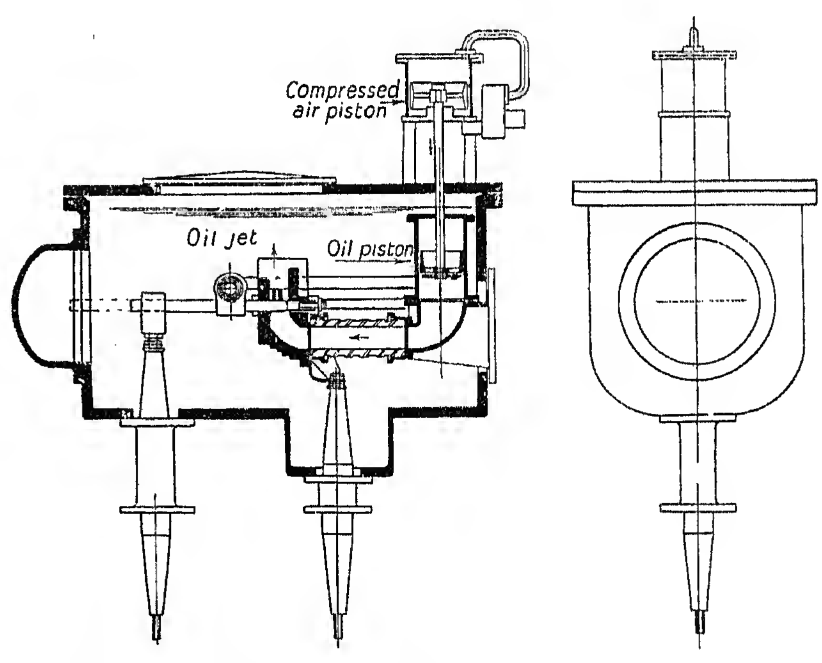


Fig. M.—66-kV single-break oil impulse circuit-breaker.

position. By this means the discharge currents associated with the over-voltages are interrupted without the supply circuit itself being interrupted at the same time. The full duration of the flow of the power current is of the order of 1–3 cycles, and thus the normal protective gear is left inoperative.

With regard to the busbar arrangement shown in Fig. 3, it appears a tremendous complication to make the busbars into one series of isolating switches. I cannot

agree that our record of service with regard to switchgear insulation could justify such complications as those indicated in order to obtain the degree of accessibility and interchange which this arrangement affords. I feel that the isolating switches and links tend to be inherently weak from the insulation point of view, and possibly also as regards current-carrying capability, apart from the fact that the method introduces more things to go wrong than past experience would indicate as necessary. It may be that Fig. 3 is intended to represent a practicable form by which the maximum degree of interchangeability is obtained, but not necessarily one which would be recommended universally. Perhaps the authors would comment on the suggestion that for general purposes a smaller degree of sectionalization would be more practicable, and perhaps they would indicate the locations for which their arrangement is particularly intended.

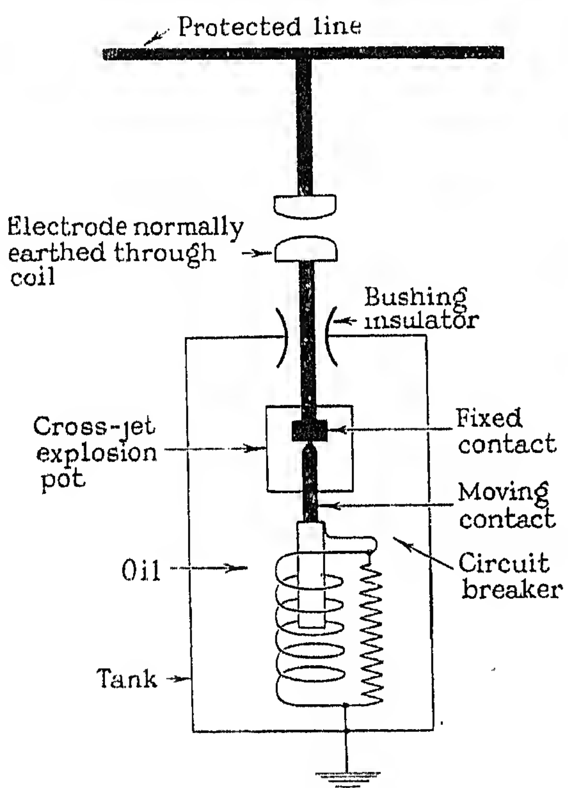


Fig. N

Mr. P. G. Ashley: On pages 451 and 452 over-voltage and quality tests on insulation are mentioned as being the main feature of routine safeguards. Over-voltage tests are open to the objection that they may result in a component being broken down at a time which is inconvenient to the supply authority. Loss-factor tests, on the other hand, if carried out at voltages not greater than the normal working voltage, exert no stress on the dielectric.

We have been able to make a considerable improvement in the quality of our bakelite-paper bushings by studying and controlling the properties of the various materials concerned. It is not sufficient, however, that the insulation should be thoroughly proved at the time of manufacture; it must be given a reasonable chance of success in later life by proper maintenance. Instances of mal-treatment are not uncommon, and although considerable improvement in the care of insulation has taken place in the last few years, there is a need for periodic tests with such an apparatus as the Schering bridge. My experience shows without any doubt that loss-factor tests play a very important part in routine safeguards. This can be illustrated from the results obtained in service at three stations using metalclad switchgear.

In the first, flashover occurred in the spout of an 11-kV unit in a substation built near a swamp. All the evidence suggested moisture as the cause. Loss tests with a portable Schering bridge showed the plug and spout bushings to have loss factors of about 24 %. The bushings were dried out under supervision, by means of tubular heaters, and revarnished. A fresh series of tests then gave loss factors of 11 % to 14 %.

In a 33-kV station with horizontal draw-out gear, tests were taken at an interval of 3 years and except in a few isolated instances it was found that the loss factor had decreased in this period. Whereas during the first test there were 60 bushings with a loss factor of more than 15 %, 3 years later there were only 15. The load on the station had increased, producing a higher operating temperature, and the switch-room had been maintained warm and dry.

In a 66-kV station where all the bushings are oil-immersed the loss factor has decreased slightly in 4 years, but it is difficult to judge by how much, as the losses amount to less than 0·5 %.

The influence of moisture in these examples is fairly obvious. Exposure to considerable dampness results in higher power-factor, which can sometimes be normalized by drying-out operations. Precautions taken to keep the apparatus warm and dry result in a steady power-factor, and sometimes even in a reduction of its value. Removal of any chance of moisture-penetration by immersion in oil has the same beneficial result.

This is confirmed by a 4-year research which we carried out recently on a range of bushings for metalclad switchgear exposed continuously to various storage conditions. Many of the bushings were assembled in chambers, as they would be in service, and were stressed continuously at 30 % above normal working voltage. The storage conditions were cold oil, hot oil, warm dry air, ordinary atmosphere, and tropical atmosphere. The tests have shown that increase in dielectric loss is due to moisture absorption and not to chemical changes in the material itself.

Mr. M. Kaufmann: I am a little puzzled by the authors' attitude to busbar-zone protection. The very strong sentiment expressed on page 453 (vol. 82) to the effect that they " consider it essential in the interests of operating efficiency that any component of a supply system should be rapidly isolated if it becomes faulty," is difficult to reconcile with the rather weak statement on page 457: " If the supply industry is of the opinion that such interruptions of supply as have been caused in the past by fires resulting from sustained arcing are regarded as a menace and an uneconomic risk for the future, the authors suggest that one of the primary steps to be taken is the provision of more adequate safeguards against the persistence of fault currents in hitherto unprotected busbar zones, which may extend to interconnecting cables and cable boxes." Surely, in view of the disastrous consequences, illustrated in Fig. 5, of a fault in an unprotected zone, there must be a whole-hearted insistence on the installation of Petersen arc-suppressors or injected-voltage arc-suppressors, or an equally wholehearted insistence on the installation of what the authors describe as adequate protective safeguards.

There may be something to be said for not wishing to frighten people by too strong an insistence on protective measures (though one of the statements I have quoted does not support that view), and the suggestion (page 457) that combined manual and automatic protection should be used may be a concession to timidity. I see no reason for timidity, unless it is on account of the " master tripping relay." But there is no need to employ master tripping relays whereby a single relay can isolate a whole section of busbars. It is possible to equip each circuit with its own relay, so that no relay controls more than one circuit-breaker. It is also possible to provide at least one independent check, so that at least two remote contingencies must arise before inadvertent tripping can occur. When in addition suitable means are provided for supervising the integrity of the current-transformer windings and connections, it seems morally reprehensible to put any responsibility on the operating engineer.

My own experience leads me to suggest that the circumstances surrounding busbar faults and their effects are too incalculable, and such faults should be left to automatic devices. It is more than probable that the smoke and fumes that render the leakage ammeter unnecessary at the same time as they make it invisible, will also prevent the operator from finding the knob which controls the master tripping relay.

Mr. J. H. Gibson (*communicated*): Four types of busbar protection are dealt with by the authors, namely leakage-to-frame, balance, balance-interlock, and interlock-time.

With regard to the first type, I shall be interested to know whether the authors consider that the supporting pedestal of the switchgear should be lightly insulated from the concrete floor, or whether such a floor forms a sufficiently high resistance to earth. It is presumed that in the event of a switchboard having more than one incoming feeder, each feeder would be fitted with a core-balance transformer, these being summated together, then connected to the check relay.

The authors give schematic details of the other three types in Figs. 11, 12, and 13, and it would be of great interest if they would give a comprehensive description of each form, together with a complete diagram of connections detailing the function of the various master-alarm tripping relays, lock-out relays, etc. I should also like to know whether special current-transformers are required for these forms of busbar-zone protection, or whether the normal instrument-transformers could be used.

[The authors' reply to this discussion will be published later.]

NORTH MIDLAND CENTRE, AT LEEDS, 25TH OCTOBER, 1938

Mr. W. T. J. Atkins: Of the many subjects dealt with in this paper, I wish to refer only to earthing arrangements and to busbar-zone protection.

Earthing impedances usually take the form of resistors, having ohmic values which are chosen somewhat arbitrarily. They are normally supplied by the makers of switchgear, generators, etc., as incidental items, and the views of their suppliers are naturally limited to the needs of the particular types of plant they are to manufacture. This is rather an unfortunate state of affairs, as earthing impedances should properly be designed with regard to the whole of the characteristics of the system with which they are intended to operate.

The obvious functions of earthing impedances are: firstly, to limit earth-fault currents to a value which will minimize damage to plant; secondly, to permit sufficient current to flow to operate earth-fault protective devices; and thirdly, to prevent the occurrence of abnormal voltages under what are termed " arcing earth " conditions. There are, however, other considerations to be taken into account. In an extensive cable network, the zero phase-sequence charging current is by no means negligible; it amounts to about 30 kVA per circuit mile at 11 kV, and approaches 200 kVA per circuit mile at 33 kV. The total fault-current may therefore be considered to be compounded of that part which is deter-

mined by the resistance of the neutral earthing device, and of that part of the charging current which is left unbalanced by the reactive current taken by the earthing device.

I suggest that a suitable design of earthing impedance should take all these matters into consideration, and that it should be practicable to reduce earth-fault currents considerably below the 2 000 amperes or so which produce the effects shown in the authors' film.

As regards busbar protection, the authors strongly advocate "unit" types of equipment for important concentrations of plant. Whilst there can be no denying the importance of safe clearance of faults from busbars, the most suitable apparatus for the purpose is, I think, very much a matter of opinion. The complexity of unit systems is by no means indicated in the schematic diagrams reproduced in the paper. Necessarily, any such system involves interconnection between all of its many parts, and, in spite of the self-checking and other safeguarding features, it implies carrying all the eggs in one basket. The authors themselves describe an arrangement whereby one does not allow the protective scheme to do its worst, but throws the onus of responsibility on the operating staff. I think that is altogether an unfair condition, and is a half-measure indicating lack of real faith in the protective devices.

In protective schemes generally, simplicity is of the greatest importance, and I feel that the alternative plan of graded earth-leakage which does not involve a complicated system of interconnection between the various parts, is far less likely to give trouble. If there is difficulty with one component it does not entail complete disaster, and if the neutral earthing arrangements are rationally designed, thereby limiting the fault current in preference to the fault duration, one can afford to let earth faults persist for sufficient time to allow a time-discriminative system of protection to be effective.

Mr. A. C. Bailey: In Section (2) of the paper it is stated that "the first general safeguard is the installation of reliable components of adequate rating and performance proved by actual tests." That, of course, is the dream of all operating engineers, but progress in the design of apparatus is so rapid that nearly all systems are saddled with obsolescent apparatus, with the result that the latest protective schemes cannot be wholly applied to get the best discrimination.

On pages 451 and 452 the authors indicate that they do not like over-voltage routine tests. I am not in full agreement with them on that point, but I am glad to see that they point out the weaknesses of d.c. voltage tests in that they do not simulate a.c. conditions of working, as the voltage gradient throughout the insulation is not the same in the two cases. If, however, one wishes to carry out routine testing of long cables there is no alternative to d.c. over-voltage tests, and I am familiar with several cases in which incipient faults in cables have been shown up by such tests. The d.c. test voltage should not exceed 3 times the working voltage.

I do not agree that insulation-resistance tests are not useful as routine tests, as suggested in the paper. I know of many cases in which defective 33-kV outdoor oil circuit-breaker bushings have been picked out by a 1 000-volt insulation tester reading to 2 000 MΩ. I believe that portable insulation testers are now obtainable which will generate up to 3 000 volts.

I agree with the authors regarding power-factor tests, but would point out that we cannot generally split up the apparatus into small portions, for which such a test is of use.

I am glad to know that the trend of development in the future will be to permit segregation of the parts of the switchgear so that each part can receive a power-factor test. I have had much experience in carrying out power-factor tests with the Doble apparatus, and the results have led us to take out of circuit many bushings, especially on outdoor oil circuit-breakers, in which there were incipient faults. We have used an outfit giving a test voltage of 10 kV on 33-kV to 66-kV apparatus. I feel sure that 10 kV is a high enough voltage to detect faulty apparatus, and in fact it has been successfully used in the U.S.A. for testing 110-kV gear. Again referring to the question of routine tests, which of course are really for the purpose of anticipating faults and then removing the faulty apparatus before a fault occurs, I am surprised that the authors omit to mention the use of voltage-grading sticks for checking the voltage gradient of insulator strings on overhead lines and also of post-type insulators in outdoor substations. This apparatus is exceedingly easy to use, and tests are carried out with the line in commission. By such tests one can find out whether the insulation is in a healthy state.

Busbar-zone protection seems to me to be worth while. Generally speaking one cannot take the drastic measure of applying the relay contacts to all the oil-circuit-breakers which are normally on the particular busbar, because there are times when one of these breakers may be connected to another busbar. I think that probably the difficulty could be overcome by having a series of auxiliary switches in the trip wiring and only tripping out the oil circuit-breakers which are connected to the faulty busbar and the busbar coupler.

With reference to expulsion gaps and lightning arresters, I know that in the past such apparatus connected to a line was a far greater hazard than lightning itself. We had many cases where a lightning discharge was followed by a power arc and this tripped out the circuit-breaker. A lightning arrester ought not to be costly, because to obtain efficient protection it will be necessary to have many of these devices spread along an overhead line; they should not be confined to the terminal points.

Mr. F. S. Naylor: While the paper deals mainly with conditions in the supply industry, it does not touch on those prevailing in the undertakings associated with large industrial works. It must not be overlooked that some of these industrial undertakings have outputs considerably in excess of that of the average supply undertaking. I have found that in industrial undertakings the conditions are rather different, particularly in regard to the rating of h.t. switchgear. At a large number of points a switch which is safe for a single B–3–MB cycle is quite adequate, and the B–3–MB–3–MB cycle laid down in B.S.S. No. 116—1937 is unnecessarily severe. One of the best-known manufacturers of switchgear in this country is prepared to rate certain switches at 250 MVA on the B–3–MB cycle but at only 150 MVA on the more onerous

B-3-MB-3-MB cycle. It is obviously desirable in a supply undertaking to cater for a number of severe operations, but in the type of undertaking which I have described there are many instances where a single operation only is called for, after which there is available adequate time to carry out a thorough inspection and a tracing and clearing of the fault. It may therefore be possible in selecting circuit-breakers for industrial working to employ a different class of rating.

The authors refer to a "small-oil-volume" single-break pneumatically operated circuit-breaker. This latest example of English practice has a definite trend toward the class of gear which has been manufactured on the Continent for some years. We have in the undertaking with which I am associated a number of breakers of this latter type for controlling large arc furnaces having capacities of 4 000 to 6 000 kVA. These switches are called upon to carry out as many as 500 operations per week. They carry out these duties remarkably well on the whole, although we have had at times considerable trouble with them, mainly due to the fact that the mechanical construction is not of that robust type one sees in British equipment. I suggest that it is high time English manufacturers gave consideration to this class of breaker, which I believe to be the solution to a large number of problems with which we are at present faced.

Mr. R. M. Longman: This paper shows that there is plenty of work and scope for the protection engineer, and the fact that as many as 34 relays are now installed on one protective panel emphasizes the need of careful routine testing.

Busbar protection is not a new idea, as schemes of this sort were discussed 20 years ago. Its revival may be partly due to the use of solid insulation in metalclad gear.

The order of reliability of insulation materials seems to be: (1) gas, (2) liquid, (3) solid; and in the more recent developments described by the authors the amount of solid insulation is reduced and liquid or even gaseous insulation substituted. All methods of protection, especially for busbars, must be kept as simple as possible, and the human element must as far as possible be eliminated.

The Petersen-coil system is preferable to voltage-coil injection, as the coil is in circuit and the protection is not dependent upon the correct relays operating.

Testing in situ is most valuable, and particularly power-factor testing, although this is difficult to carry out. Direct-current testing with reasonable voltages can give reliable information. No mention of live-line testing of insulators has been made in this discussion, but this is proving of the greatest value in detecting faulty units in a string, or defective insulators.

[The authors' reply to this discussion will be published later.]

ADDITIONAL COMMUNICATIONS TO THE DISCUSSION BEFORE THE INSTITUTION

Mr. J. A. Harle (*communicated*): As an adjunct to efficient maintenance, quality testing, such as power-factor or watts-loss testing, can be carried out on the insulation of either open-type gear or metalclad gear provided that it is known at the time of installation that it is intended to carry out such tests. For example, the casings of each unit of metalclad switchgear can be insulated from the adjacent ones by relatively light insulation, and earthed to the earthing bar only by means of removable copper earthing strips. Similarly, bakelized-paper or other insulators can be provided with earth shields or earth bands lightly insulated from the metal enclosing casings, except for a special earthing tail or strip that can be disconnected from earth when it is desired to test. Also, if desired, special test screens provided with removable earthing strips may be embodied between phases, so that the between-phase insulation can be tested.

The method of testing that would be employed would be to supply each phase of the equipment under test in turn with a suitable test voltage and to measure the losses of each unit of the equipment in turn by disconnecting the earth lead of the unit and inserting a suitable measuring device between the unit and earth. Such a device can consist of one arm of a Schering bridge or of the current coil of a suitable wattmeter. If this is done, each unit of the gear can be tested in turn, and by employing a suitable method of recording the results progressive deterioration of the insulation in the unit can be observed.

The extent of application of such schemes is limited only by practicability, as theoretically there is no reason why insulation of equipment should not be automatically tested at its working voltage (i.e. when live). This could be done by making a suitable selector switch open each earth-connection in turn and insert measuring apparatus. The value and phase angle of the current in the connection would then be compared against a selected standard value representing the initial quality of the insulation, in such a manner that any deviation of current from the standard value would automatically operate an alarm or even switch out the section of the equipment in question. For example, this could be done by using Schering-bridge methods utilizing preset values of resistance and capacitance in one arm of the bridge, representing the quality characteristic of the insulation of the component under test, and deflecting detectors arranged to make contact when the deviation of quality from standard exceeds a certain amount. There is, however, the practical difficulty that the selector equipment must be capable of withstanding earth-fault currents in the event of faults to earth, and possibly full short-circuit currents in the event of simultaneous faults, conditions which render the scheme extremely difficult to apply.

Mr. I. W. A. Kirkwood (*communicated*): The authors refer generally to the application of periodical site-tests of insulation, and in particular to the advantages of watts-loss testing, which I believe will be used more widely as the principles involved become better known throughout the industry. In addition to the apparatus referred to by the authors, various other types of apparatus, including a portable Schering bridge, have been evolved from time to time. To obtain the maximum benefit, the tests should be made at voltages as near as possible to the working voltages of the insulators, and 10 kV has generally been found to be the most satisfactory

compromise for portable apparatus of this description. Other types, transportable rather than portable, have been developed for higher test-voltages.

Some speakers have criticized the principle of metal-clad switchgear on the ground that routine tests of individual insulators on busbar runs are impracticable without physically separating the insulators. Although provision for such tests can readily be made in new types of switchgear, it is possibly difficult to apply them to older types.

One method that has been adopted for some of the older types is to use an expanding electrode such as is shown in Fig. O. This is inserted a predetermined distance into the orifice of the insulator to be tested, and the power factor is measured in the usual way. The advantage over the more usual but somewhat crude method of springing a copper-foil strip into the insulator is that intimate contact with the electrode surface is assured. If desired, the surface of the electrode may also be smeared with a thin coating of vaseline, but this has generally been found unnecessary. In spite of its frequently great value, this method is sometimes undesirable, e.g. if the insulator contains stress-grading layers in some particular arrangements, and hence it may be of interest to describe a method of testing without physical separation, worked out after considerable research by the company with which I am associated. It is based on the ascertained fact that the power factor of an insulator increases with increase of temperature in a way usually dependent on its initial power-factor, and it consists in measuring the power factor of all the insulators connected in series when they are cold, and then heating each insulator in turn to a predetermined temperature and measuring again to find the increase. A convenient and practical means of heating is an ordinary low-watts carbon-filament lamp. It is usually found that a comparatively low temperature, such as 40° C. to 50° C., is satisfactory, and it is only necessary to ensure that each insulator is at approximately the same temperature when it is tested, and that each heated insulator is allowed to cool before the next test. The method is perhaps somewhat slow; but on the other hand heating-times of 10 to 30 minutes, depending on the size and design of the insulators, have been found satisfactory, and these are much shorter than would be required to cut the chambers apart. In addition, it is not necessary to disturb the switchgear in any way, and the time required for testing a complete board is relatively decreased because all the phases can be dealt with simultaneously.

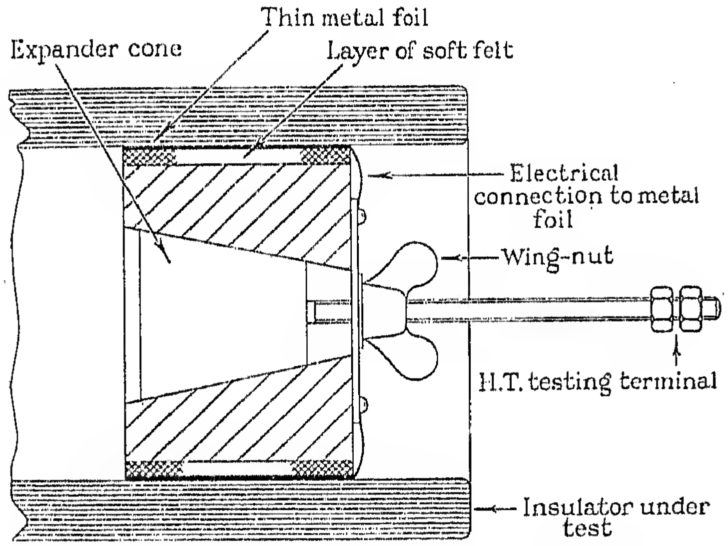


Fig. O.—Expanding electrode for power-factor tests.

In conclusion, one very important fact must be stressed, namely that the co-operation of the supplier of the gear should be obtained in endeavouring to determine the condition of any insulator from values of power factor. The power factor is influenced in a number of different ways, not the least important of which depends upon the raw materials from which an insulator is made; and the important thing is not so much its absolute value as its stability over a number of years. Although site power-factor testing is not new, it is only just coming into popularity owing to the development of portable site-testing equipment. Most manufacturers have used it as a works routine-test for a number of years, and are therefore able to give a more reliable opinion on the stability of insulation than could possibly be obtained from any other source.

Mr. A. E. F. Spence (South Africa) (*communicated*): On page 462 (vol. 82) the authors refer to the use of low footing-resistances for towers, as a means of preventing flashovers on an overhead line. I am not quite sure about this. Does it mean that if an insulator flashes to earth on a tower with special earth-plates, i.e. low footing resistance, the action of the protective gear is rendered more certain?

In connection with high-speed opening and closing of oil switches, is there not some risk of producing voltage surges on the system which might cause operation of other protective devices? As this practice is fairly common, it seems that this difficulty does not occur, or has been overcome.

I am interested in the type of switch, shown in Fig. 17, having rotary moving contacts and reduced oil volume, and I should like to know whether this switch has an extended application and in what sizes it is made. I should like also to emphasize the important part played by the auxiliary switches in series with the tripping circuit. Regular inspection ensures that the switches are clean and that they make and break properly; but there is a trouble which is more difficult to guard against, namely breakages of some part of the fixed or moving contacts. It seems as if these components occasionally leave something to be desired in their design. Controller-type switches are sometimes liable to weakness at the point where the contact fingers are attached to the base, and, if fracture occurs there, those responsible are lucky if they find out in time. What is called "modern design" does not always help, largely because price-cutting is apt to lower the quality of a product almost as much as scientific progress raises it.

[The authors' reply to these communications will be published later.]

MEETING HELD AT DUNEDIN, NEW ZEALAND, 14TH JANUARY, 1938

Mr. M. C. Henderson: For many years we at Dunedin had no automatic protection on our main lines; failure of an insulator meant a complete shutdown until the trouble had been located and isolated. In those days, reliability of supply was not considered so important as it is to-day, but, with the growth of load and the many interests involved, the necessity for automatic protection became imperative, and this was installed about 10 years ago. It has proved eminently satisfactory, so that an extensive shutdown from electrical causes is now very infrequent.

Interconnection with Waitaki has proved very advantageous and has provided an ideal stand-by plant, but new complications are introduced when power is derived from two or more sources. This was exemplified a few weeks ago when Dunedin had a "blackout" owing to a fault which upset the normal conditions of the protective relays, and interconnection in this case proved a disadvantage. Our problem at present is how to overcome this difficulty in future.

Interconnection of various sources of supply raises the question of the rupturing capacity of circuit-breakers, and makes it necessary to scrap or reconstruct plant that was quite capable of dealing with any conditions that could possibly arise while the systems were isolated and independent. This matter was fully investigated and attended to before interconnection with Waitaki took place. A considerable amount of switchgear had to be scrapped although it was only 10 years old, and it was replaced by modern plant capable of dealing with any possible contingency under the new conditions; although we have had a number of severe short-circuits during the last 3 years, since interconnection commenced, the breakers have never failed to clear the lines satisfactorily.

Mr. I. Dalmer: It would be a great advantage if switchgear manufacturers would produce more reliable isolating and reclosing gear. Such gear is badly needed in Power Board operation in New Zealand, where we have to deal mainly with isolated feeders.

Mr. G. T. Edgar: I should be glad of some further description of the high-voltage bushing insulators shown in Fig. 17. Are they of the oil-filled or the condenser type? Also, do British manufacturers consider that condenser-type bushings should be used for certain purposes rather than the oil-filled type? Has there been any further development with reference to these bushings since the paper was written?

Protection against earth leakage, with particular reference to fallen h.t. feeder wires, is a matter of great concern to distribution engineers in this country. As an example, last winter we had a fallen 6 000-volt bare line draped along a wire fence, thus preventing sufficient current from passing to earth to operate the earth-leakage relays. On this line a 20/5 current transformer is installed, and the line leakage current necessary to trip the breaker is 1·9 amperes, which is considerably under the maximum leakage current of $12\frac{1}{2}$ % allowed by the Public Works Department Regulations. Have any of the British firms developed a relay to meet the above case better than the one already available from the Continent?

Mr. R. D. Veitch: I should be glad if the authors could describe the tests that were carried out to obtain the data given in Table 1. In the footnote to this Table it is stated: "Peak amperes = r.m.s. amperes $\times \sqrt{2} \times 1 \cdot 8$" (i.e. Peak amperes = $2 \cdot 55 \times$ r.m.s. amperes). The crest factor of a sine wave is very much smaller than $2 \cdot 55$: what is the explanation?

As regards short-circuits on supply systems, is there any means with the exception of series reactors or resistances whereby the short-circuit kVA may be limited?

On page 451 (vol. 82) it is stated that the over-voltage test cannot possibly indicate in itself that insulation has been strained. I should like to ask whether such tests do not form a necessary preliminary to the finding of weaknesses by insulation-resistance tests.

Testing by what is described as the power-factor test is recommended. Does this mean the measuring of the resistance and the capacitance of the insulation, and, if so, would not the shifting of the insulation in normal service conditions alter these figures to a considerable extent? What provision is made to ensure that all parts of the insulation are tested always at the same temperature? This question will have a considerable bearing on the tests if they are to be tabulated as suggested and compared with other tests. Will the authors describe satisfactory methods of measuring the capacitance on site?

On page 454 it is stated that "supply systems including cables are not subject to excess voltage caused by lightning"; will the authors enlarge on this point? It has been the experience in New Zealand that supply systems including cables *are* subject to excess voltages caused by lightning.

I understand that protective systems whose operation depends on alterations in the capacitance of the lines have been tried out in situations where earths are poor. Are these at all satisfactory, and have they been used extensively?

In regard to resistance earthing, the supply systems here are practically all solidly earthed. Is there any great advantage in resistance earthing, and, if so, what sort of resistances are used, and how are their sizes calculated?

It is stated by the authors that high-speed operation of protective systems is difficult with directional relays. Is this due to the fact that directional relays are slower than the ordinary relays?

Turning to page 455, I should be glad if the authors would explain further their point regarding oscillations of the primary supply system having a frequency in excess of the third-harmonic frequency.

Can they give any information as to arc-suppression by Petersen coils and arc-suppression by voltage injection? Are these systems used much in practice?

Counterpoises are mentioned in the paper, and I should welcome a brief description of their use.

Expulsion gaps and lightning arresters are treated separately by the authors, whereas we generally describe them both as lightning arresters. Where is the line drawn?

I understand that Petersen coils are tuned so as to offset the resultant of the capacitance currents of the two sound phases; but, in most systems, would not that capacitance current be only a small proportion of the full fault

current, and out of phase with it? Would not the larger proportion of the fault current, which is apparently flowing through a pure resistance, be left unaffected, except by the resistance of the Petersen coil?

In view of the fact that arc suppression by Petersen coil and by voltage injection raises the potential of the neutral point a considerable amount, the potential of the two sound phases must be raised a corresponding amount, to a maximum of 1·732 of the value under normal conditions. In this country the insulation on transformers is not, as a general rule, graded, and the result is that the end of the transformer winding connected to the neutral is quite as heavily insulated as the end connected to the line. Raising the neutral voltage would not damage this end of the winding. Would it be advisable, with such transformers in circuit, to insert Petersen coils or introduce voltage injection? Would not the high-voltage end of the transformer winding be stressed considerably by its normal working voltage?

It is mentioned in the paper that sphere-gap absorbers are faster than others, but it appears to me that a sharp-ended absorber would be the faster. Is there any reason why a sphere-gap absorber should be faster than gaps of other shapes?

As regards the quenching of the arc in a circuit-breaker, some 6 years ago there was developed on the Continent a water-blast circuit-breaker for 6 kV. Did anything ever come of it?

The paper advocates the rapid sectionalization of faults: where short-circuit currents are small, would the authors recommend delayed sectionalization of the fault in the hope of blowing off the fault?

Table 5 shows that the breaking time of the circuit-breaker from the time of closing of the trip-coil circuit to the instant of opening of the breaker is only 11 cycles, or a little over one-fifth of a second; but it appears to me that one of the big factors influencing this time-period would be the time that the relays take to operate and close the trip-coil circuit. What would that time be, with rapid-acting relays?

Mr. S. O. Hughes: I should like to ask the authors whether the continuous functioning of the earthing device would not only prevent the consequential faults on the white and blue phases but also localize the interruption of supply to Switch-house A. In other words, would not the authors' "unprotected zone," be conditional upon the isolation of the neutral point?

[The authors' reply to this discussion will be published later.]

MEETING HELD AT CHRISTCHURCH, NEW ZEALAND, 18TH JANUARY, 1938

Mr. H. C. Brent: I should like to say a few words from the point of view of a consumer—the Post Office. Although the Post Office as a whole is a consumer in a large way, it is not this aspect that is so important as the fact that continuity of power supply is considered to be an essential feature in the furnishing of telephone and telegraph service.

Now, it is appreciated that a totally uninterrupted supply of electrical power is a practical impossibility. Even if such were physically possible it would be ruled out by economic conditions. This being the case, the Department has to consider auxiliary or emergency plant. In this connection the following points need attention: (1) The reliability of the normal power supply. (2) The most suitable emergency plant to take the place temporarily of the normal power supply. (3) The quickest practical method of making the change-over from normal to emergency power.

The system devised on account of both emergency and other considerations consists in the use of a secondary battery as a buffer. This battery is normally charged by an electric motor-driven generator which in an emergency is driven by, say, a petrol engine. In some cases, however, the battery is large enough to constitute the emergency supply for a short period of time.

The effect of a power short-circuit on the nearby telephone circuit is also most important as involving the risk of injury to persons, plant, and buildings. Persons may be injured by receiving acoustic shock and thus having their nervous system deranged, or being deafened. Also, telephone linemen receiving an electric shock (produced by induction) may fall off a pole and thus be killed or maimed. Plant may be injured as a result of strong induced currents or high potentials. Buildings may be damaged as a result of fire; this feature is less important than the other two, as communication circuits are usually adequately protected and induced fault currents usually persist for only very short periods of time.

In their endeavour to safeguard power systems from interruptions engineers find themselves "between the devil and the deep blue sea." If they over-protect the power circuits by very quick-acting or finely-adjusted circuit-breakers or relays, then the number of interruptions is increased; whilst if their circuit-breakers are slow-acting or "reclosing" under certain conditions, then there is inadequate protection.

Mr. J. C. Forsyth: Regarding the required rupturing capacity of switchgear and the current-carrying capacity of cables, calculated from short-circuit conditions, it seems doubtful whether every fault occurring on the system would produce the effect indicated by such calculation; what is the probability of the calculated result being experienced in practice? In other words, if a given number of faults on a system are considered, what percentage are likely to produce on the switchgear the result obtained from the calculation based on assumed short-circuit conditions?

Regarding routine tests, in Christchurch we never make high-voltage tests on equipment after it has once been put into service, as we feel that these tests may cause damage which would not be immediately apparent and thus might later result in a breakdown. We have made a practice of insulation-testing the 11 000-volt switchgear in our main substations at regular periods, with a 2 500-volt insulation-tester. While such a practice has its limitations, it has on one occasion at least enabled us to discover a faulty insulator on a particular circuit-breaker and to replace it before breakdown occurred. No attempt has been made to undertake power-factor

tests, but information on this subject is being collected, particularly data relating to experience elsewhere.

The paper mentions the effect of earthing the neutral through a resistance in keeping system faults within desirable limits. It was the practice of the local generating authority, until a few years ago, to earth the neutral of the 11 000-volt system through a resistance, but at that time the resistance was removed and the neutral solidly earthed. This was done in order to permit of the installation of a particular type of protective gear on the transmission system. This may have been sufficient reason from the generating authority's point of view, but unfortunately it resulted in rather adverse conditions for the distribution authorities supplied from the system.

In New Zealand the use of balance feeder-protection equipment has not always been given the consideration it deserves. This is no doubt primarily due to it having been assumed that the cost of such a system was prohibitive on account of the expense of the necessary pilot cable. This should not be accepted as axiomatic, and each case should be carefully investigated before it is decided to adopt other methods. In a recent case investigated locally of parallel-feeder protection, it was found that owing to the number of expensive relays required for other suitable schemes to give corresponding performance, the installation of pilot-wire balance protection was the better proposition. This was chiefly due to the simplified relays now available, and to the simple 2- or 3-core pilot cable required for the newer systems of this type.

The ever-present possibility of fire, with the likelihood of very serious damage to vital equipment which can only be obtained from the country of manufacture after a very lengthy delay, is a serious matter in a country like New Zealand, situated so far from the manufacturing centres. Consequently the statement in the paper that experience has proved that the root cause of fires and explosions is uncontrolled sustained arcing, and the further statement that such arcing can be prevented by the use of suitable precautions, are very reassuring.

We in Christchurch have had practically no experience of the use of automatic reclosing gear because the greater part of our primary distribution system is underground. The use of such equipment is no doubt satisfactory in transmission systems where the lines are entirely clear of trees and similar sources of trouble, but on rural reticulation lines in this country considerable trouble arises from the proximity of trees. Cases have occurred where reclosing gear has operated when conductors have been held in contact by trees or branches falling across them, with the result that the switchgear in circuit has been seriously damaged.

The paper mentions the pronounced effect that the interconnection of generating stations has in increasing the risk of serious damage on the occurrence of a fault. In New Zealand the interconnection of large generating stations has not been an unmixed blessing. Some doubt has arisen as to the wisdom of developing sources requiring such interconnection, at the present time at least, and the reading of this paper has not helped to dispel that doubt. In this country, generation is chiefly in the hands of the hydro-electric branch of the Public Works Department, whereas distribution is with one exception in the hands of local bodies each dealing with its own comparatively small area of supply. No doubt the generating authority in this country feels that it has ample reason for such interconnection, but its reflection on the various distribution authorities is a very different matter, since it produces effects which they cannot predict. It consequently results in a position in which the distribution authority finds it extremely difficult to ensure at all times that the design of its system is efficient and satisfactory and that the equipment used is adequate for its purpose. Since supply is obtained entirely from water power, the desire for interconnection arising from the need for extreme efficiency in generation does not arise, and the primary consideration is continuity of supply. It would appear that this could be more economically and satisfactorily achieved if the country were divided into separate districts, each supplied from a separate generating system. High-class design and the use of first-quality equipment in both the generating station and the transmission system would then ensure a sufficient standard of performance as far as continuity is concerned, particularly when it is remembered that the protective equipment required in this case would be less costly, much less complicated, and therefore probably much more effective than in the case of interconnection. The local use of an elaborate protective scheme for the interconnected transmission system has not been entirely successful in eliminating interruptions to supply following surges resulting from faults on the system. If separate generating systems were adopted the distribution authorities would derive great benefit from the smaller rupturing capacity required in switchgear, the possibility of predicting future requirements with some degree of certainty, and the resulting greater confidence in the adequacy of equipment for a reasonable period in the future.

Mr. J. R. Templin: The paper sets forth the present-day requirements in regard to safety in switchgear protection devices, and engineers in New Zealand should use it as a foundation in designing future protective equipment. It should, however, be pointed out that the small electrical demands of various generating and distribution authorities in this country compared with those of Great Britain make it economically impossible for us to carry out all the recommendations contained in the paper.

Prof. P. H. Powell: Recent electrical developments seem to have been chiefly connected with auxiliary apparatus. Main generating plant has altered little except as regards output capacity, whereas the increase in the use of protective gear of some type or other and the increase in the extent of the protection offered have been very marked.

Protective gear is of the nature of an insurance, and hence its cost must be compared with the cost of the outage it is intended to prevent. Again, every additional piece of apparatus is an additional potential weakness, and may mean increased difficulty in restoring service under abnormal conditions. For these reasons I have not been quite certain that the additional protection aimed at is always secured, and I think that it might often be better to spend more in ensuring that the quality of the main

plant is of the highest—and less on the extra protective gear.

The enormous possible output of modern stations has correspondingly increased the duty of circuit-breakers; this is especially important where a substation originally designed to receive its power from a small plant is linked with a main system, or when the plant is augmented, as was the case locally when the linking of the Waitaki plant to the Lake Coleridge system largely increased the energy that might have to be dealt with at the local substations. In such cases, possibly, more attention should be paid to current-limiting devices and sectionalization to localize the effects of a fault.

Over-voltage testing of insulators gives very little information, and may easily do harm. The power-factor or loss test, if records are properly kept, should give much more useful information. The authors do not appear to place great faith in routine test work, and imply that tests made by manufacturers during construction are sufficient; they do not specify the nature of these tests, and imply a confidence in manufacturers' methods which is possibly not always shared by other engineers.

In the case of overhead (rural) systems many faults are of a transitory nature and the use of automatic reclosing gear is often satisfactory. The circuit-breakers, after a certain number of operations, remain open till reset by hand, and are often installed in unattended substations. I understand that it is customary for the operator, when investigating, to attempt to make the wire live. This I consider to be a dangerous practice which should not be permitted, for, supposing the line broken and lying on the ground, the operation of the automatic gear has rendered it dead very shortly after the break occurred and the wire has been lying apparently innocuous for a time which may be minutes or hours. Suddenly to apply voltage to such a wire might result in a fatality.

Two new designs of high-speed circuit-breakers are shown in the paper. It occurs to me that in the rotary type the electromagnetic forces that are present will tend to open the switch, and chattering may occur at the instant of contact on load. I presume that this point has been investigated. Electrical engineers will perhaps be disappointed at the substitution of pneumatic gear for electromagnetic in the other type of circuit-breaker, but they should realize that each type has its own particular advantages and limitations. The possible pressure that can be obtained by an electromagnet is less than that obtainable by means of compressed air; or perhaps I should say that the ratio of force to mass can be made greater in the pneumatically-operated than in the electromagnetically-operated gear, and thus greater rapidity of operation is possible.

In his verbal summary of the paper Mr. Clothier referred to a special quick-acting spark-gap; it would be of interest to have some information concerning its impulse ratio and further details of its performance.

Mr. H. G. Kemp: There is one general feature of the paper which surprises me, and that is the underlying suggestion that it is the practice in some places to leave important equipment open to sustained arcing under fault conditions; probably, however, such conditions occur more in generating than in distributing stations.

I propose to confine my remarks on the paper to protective equipment in distributing stations in rural areas operated at the usual voltage in New Zealand of 11 kV.

The conditions prevailing in such an area may be of special interest, as a comparatively small normal operating current may occur in conjunction with a relatively high short-circuit current, while the local circumstances in regard to class of load supplied, revenue, etc., may not warrant elaborate arrangements for absolute continuity of supply, provided that long interruptions can be avoided. The demand for absolute continuity is easily developed and may result in heavy expenditure on equipment and on maintenance methods. I do not believe in encouraging the growth of such a demand in rural areas.

Through the interconnection of the Waitaki and Coleridge power stations recently, with the consequent increase in the possible short-circuit currents, I was faced with the replacement of the 11-kV switchgear in our main distributing station at Ashburton, where the old gear was of inadequate rupturing capacity. At Ashburton we have a normal demand of a little over 2 000 kW, with feeder currents ranging up to 30 amperes, while the rupturing capacity necessary in the switchgear is calculated at 130 MVA. The old switchgear was of the indoor sheet-steel cubicle type. The requirements at Ashburton appeared to me to be as follows: (1) The safeguarding of the busbar zone. (2) The rapid clearance of fault conditions arising in the busbar zone or on the distribution lines. (3) The reasonably rapid restoration of supply, absolute continuity of supply not being essential. (4) The installation to be as simple and inexpensive as the foregoing would permit.

As it has become almost a convention in the electric supply industry that 11-kV switchgear should be of the indoor type, this type was considered first for the new installation at Ashburton, and it was apparent that a new switch-house would be required to accommodate it. I discussed the problem with a local engineer, who suggested that outdoor equipment might be worth consideration. The proposal appealed to me for several reasons: (*a*) It provided for a large degree of physical separation of all components in the busbar zone. (*b*) It permitted full access to all components, and their easy replacement in the event of trouble. (*c*) All feeders from Ashburton being overhead, it avoided the use of underground cables and boxes. (*d*) It reduced to a minimum the amount of insulation required. (*e*) In the event of insulation failures, the probable damage would be small and repairs simple. (*f*) The necessity for buildings would be avoided, and, although the equipment would be more costly, the total expenditure would be comparable with that for indoor equipment. (*g*) Ample space was available. (*h*) The change-over from old to new gear, through the absence of cable connections, would be greatly simplified.

Such an installation is possible in a rural area because of the comparative cheapness of land and the general use of overhead lines. Under city conditions, the general use of cables coupled with the high cost of substation sites make the use of the more compact metalclad gear essential.

The new Ashburton substation comprises 8 outgoing circuits, each covered by one 15-kV outdoor-type oil circuit-breaker of 150 MVA rating and three independent outdoor-type current-transformers, the unit group having gang-operated isolators on each side, with a short-circuiting air-break switch and fuse for emergency operation. The busbar arrangements provide for the normal supply through the oil circuit-breakers to the outgoing lines to be taken from a main busbar, while the emergency supply through the air-break switch is drawn from an auxiliary busbar. This arrangement permits access to either busbar in the event of busbar trouble. Supply to the busbars is given by two cables, either of which may supply either busbar, from the Public Works Department's indoor gear, the Department's oil circuit-breakers covering the busbar and cables. Inverse time-limit overcurrent and earth-leakage relays are mounted at the oil circuit-breakers, while operation is by remote electrical control from the power station. A totalizing metering equipment is provided on the main busbar only. All insulation on the structure is of at least 15-kV rating.

In my experience, the weak points in the busbar zone are the cable boxes and current transformers. Cable boxes have been practically eliminated in the arrangement I have described, while the current-transformer problem has been handled by specifying a ratio large enough to permit a construction which will carry the full short-circuit current. This ratio will not be the best for feeder metering, but this is of small importance compared with reliability in operation.

Farther out on the distribution system we have auto-reclosing circuit-breakers with the usual protective equipment, but owing to the small sizes of wire in use the problem of handling large short-circuit currents does not arise.

In general, I do not think the more elaborate protective systems are required under rural operating conditions in New Zealand. Reasonable subdivision of the supply system, with protection by overcurrent and earth-leakage relays, is sufficient.

Mr. E. Hitchcock: I would emphasize that where generation and transmission are controlled by one authority, and distribution by another, a high degree of co-ordination between the two is necessary if difficulties are to be avoided in the matter of protection against interruptions.

At one extreme of this problem, there is the case where the risk of damage is so small that it may be assessed at less than the cost of protection. At the other extreme is the case where the risk is so great that the cost of protection is abundantly justified. For most engineers the position lies somewhere between these two, and the problem is to determine the type and extent of protection warranted in the particular circumstances.

It is interesting to reflect that all the creative skill and organizing ability of those responsible for the design and production of prime movers, generators, transformers, and switchgear, and for the working of the transmission and distribution systems, can be frustrated if the electrical energy fails to reach the ultimate consumer. This is one reason why the subject of protection is beginning to outstrip other electrical subjects in importance. Another reason is that electrical supply is possessed of a sinister characteristic: it is capable of self-destruction.

These aspects of protection strongly suggest a parallel. Humanity has built up the intensely complex and delicate structure of civilization. It is lamentably capable of self-destruction. One of the worthiest causes to which human minds, including those of engineers, can be applied is the devising of protective measures whereby such a catastrophe could be avoided.

[The authors' reply to this discussion will be published later.]

MEETING HELD AT AUCKLAND, NEW ZEALAND, 24TH JANUARY, 1938

Mr. H. Bartrom: The switchgear layout shown in Fig. 3 is no doubt ideal, but to achieve this arrangement it has been necessary to incorporate no less than 96 movable contacts in the busbars of a section of switchgear comprising 6 switches. The resulting system is more likely to be subject to contact trouble than to insulation failure.

The pneumo-oil-operated circuit-breaker is certainly a method whereby the operating force is transmitted to the contact more quickly than by conventional methods.

Does the turbulator in the authors' switchgear work on a similar principle to the de-ion grid?

I should like to ask a question concerning the fire on which Mr. Clothier was called upon to report about 2 years ago. This station had modern switchgear and protective apparatus: what were the time limits of the relays?

Have busbar failures of the past warranted such extra precautions—which might prove to be hazardous—as busbar-sectionalizing of every switch, and busbar-zone protection? Some of these failures can be accounted for, and should not have occurred; they might have been brought about by over-stressing the insulation with over-voltage tests.

According to the paper, the switches S_1, S_2, and S_3 may be connected for economy on the l.t. side of the power transformer associated with the protected network; this, in many cases, could still be described as "e.h.t." Would the unbalance-voltage relays, which operate the switches, be set so low that a disturbance on some other part of the system would not affect them? The scheme would require a very positive interlock system to prevent two switches closing at the same time. What takes place when two phases have a transient fault together? In the event of a permanent earth-fault, and assuming the impedance of the earthing circuit of the protective apparatus to be high, the earth-leakage relay would have to be very sensitive to operate; also, if the impedance were of a much lower value, this would permit of a greater fault current being sustained until the cycle of operations had taken place. I presume the sequence of events in the event of a fault to be: Voltage-unbalance relay operates, completing the circuit of a contactor to close the circuit of the solenoid of the voltage-injection breaker. The fault not being a transient one, another relay would be used to connect in the ordinary protection gear. If the fault were in a pole-top switch, or other enclosed

apparatus, the increase in time-delay might cause the fault to develop into a 2-phase fault to earth. It would also be necessary to increase all time limits on the supply side, which would be departing from the principle: that the quicker the fault is cleared, the better. As a large proportion of overhead-line faults are of a transient nature, the difficulty is very efficiently overcome with auto-reclosing switches; but a slight improvement could be made if manufacturers incorporated a simple by-pass link to enable the switch to be tested occasionally. With modern high-speed relays and circuit-breakers, auto-reclosing has reached a stage where it is possible to open and close a feeder without synchronous machines dropping out.

With modern high-speed rupturing of a fault, is the stress on a breaker increased on account of the fault current having a higher d.c. component? Does the rapid de-ionization of the arc counterbalance the higher d.c. component?

Mr. C. M. Gray: However much we in New Zealand may pride ourselves on the progress we have made in the reticulation of the country, we have lagged behind in the application of adequate protection to our systems, and it is now becoming urgent that modern methods of protection be installed.

I am particularly interested in the authors' remarks in connection with fault protection by means of arc-suppression systems. I have had compiled a record of power failures on my Board's system during the last 4 years, and find that 66 % of the failures on the 11-kV lines during that period were due to transient faults; that is to say, the feeder circuit-breaker after reclosing on tripping, owing to an overload or earth-leakage fault, remained closed. While such faults may not be of great importance so far as loss of revenue is concerned, they are important from the point of view of the consumer's goodwill, particularly where manufacturing processes are interrupted and require to be restarted as a result of the stoppage of motors. It would appear, therefore, that if by means of Petersen-coil tuning or voltage injection the stoppages resulting from these faults could be eliminated, a great advance would have been made towards continuity of supply. Of the remaining permanent faults recorded, over 60 % were definite earth faults, and in these cases the faulty section had to be isolated until the fault had been located and repaired.

In New Zealand most of the supply authorities take their supply from the Public Works Department, from one or more substations in which the main transformers have a solidly earthed neutral. It would appear, therefore, that the Petersen-coil method could not be adopted for this system. The voltage-injection system seems to require that the neutral point be earthed through a resistance, and it would be interesting if the authors could give information relating to actual operating experience of this device on systems similar to those employed in New Zealand; that is to say, on 11-kV radial-feeder systems.

I should like to know also whether the operation of the apparatus is adversely affected by the fact that the line supports in general are of wood, and that none of the insulator pins or other metal fittings on the poles are earthed. Finally, in the case of a permanent earth fault, would the apparatus maintain voltage on the faulty phase, or is it possible to make the apparatus discriminate between transient and permanent faults?

Mr. W. H. Gregory: On page 448 (vol. 82) it is stated that breaking currents of 44 000 symmetrical r.m.s. amperes and corresponding making currents of about 110 000 peak amperes should not be exceeded at any voltage; I should be interested to know how these current values were obtained, and the nature of the apparatus used. Also, what exactly is meant when it is stated that at the higher voltages the current limits should be lower?

On page 452, it is stated that ohmmeter readings cannot be regarded as a useful routine site-test for predicting the state and probable life of high-voltage insulation. Although this statement bears out my own experience to a certain degree, in that apparatus has failed almost immediately after giving a high reading of insulation resistance, I am of opinion that if the method outlined by R. W. Wiseman* is used, wherein an insulation-resistance/time curve is taken, we do get a direct indication of the insulation condition. I think that if this latter method of testing were generally adopted there would be fewer failures of insulation through moisture.

Power-factor tests by means of the Schering bridge or similar apparatus are useless unless carried out at voltages above and below the rated service voltage of the apparatus under test. The experience of the Electrical Branch of the Public Works Department in New Zealand is that bushings that have partially failed, and others that have broken down, have been shown when tested by the Schering bridge to have power factors of 1·25 % and 1·5 %, which would indicate good bushings. As the test voltage of the bridge does not exceed 5 kV, it is quite obvious that tests made on bushings at voltages other than their rated voltage give incorrect results.

Another important point is that many of the earlier type of bushings which have been in service for some considerable time do not lend themselves readily to power-factor testing; and again it would appear that where the power-factor test is to be carried out on bushings as a routine test it is essential that the initial power factor of the bushing at normal voltage be obtained before it is placed in service, so that a definite indication may be given of the change in power factor of the bushings as they are tested from time to time.

Has arc-suppression by Petersen-coil tuning been adopted in England? Here in New Zealand we operate with the high-voltage neutral solidly earthed, thereby following to a great extent American practice. It would be of interest to know whether this system has been adopted in England.

Arc suppression by voltage injection seems rather an ingenious method of operating where transient earth-faults are fairly numerous, and I should be pleased if some further information could be given about this apparatus. Here in New Zealand transient faults are quite numerous, especially on secondary distribution lines, and it would appear that apparatus of this kind might help to ensure continuity of service.

I should like to know whether it is now standard practice to impulse-test all apparatus at the manu-

* *Transactions of the American I.E.E.*, 1934, vol. 53, p. 1010.

facturers' works in England. There is a fairly strong difference of opinion as to the value of impulse tests, in that many claim that where such tests are applied the apparatus is over-stressed prior to being placed in service.

Mr. T. MacLennan: Presumably certain parts of the switchgear shown in Fig. 4A could be air-insulated, and not filled with compound or oil. The provision for easily removing the various components necessarily conflicts with insulating them to the highest degree of safety, but as we probably cannot feel sure that insulation can be absolutely perfect, and that there is no risk of its failure, it appears desirable that switchgear built on the lines indicated in Fig. 4A should be given a trial. As all connections to circuit-breakers, etc., appear to be taken out through the top of the metal enclosure, it may be that oil could be used as an insulating medium.

It would be interesting if the authors could give any information on the variation of insulation resistance with direct current and with alternating current, at different voltages, to show to what extent measurements at lower voltages could be applied to the conditions prevailing at the higher voltages at which the apparatus is to operate.

On the system of the Public Works Department (New Zealand) power-factor testing of bushings has just recently been commenced. Fortunately we have some reason to hope that modern high-voltage bushings are reliable, in which case there may not be sufficient justification for such routine testing. Out of about 20 years' experience of bushings, the following may be worth recording.

On a certain type of bushing supplied by one manufacturer about 2 failures per year took place from about 1925 to 1932. The failures took place on both the original bushings and on several replacement orders, but it was noticed that there were no failures on replacements supplied after 1928. Sufficient new bushings were then ordered to replace all the earlier ones that still remained in service, and there have been no more failures.

On another type of bushing supplied by another manufacturer about 1926, a failure took place preceded for about 2 days by increasing interference with wireless sets at the substation. Attempts to locate the source of trouble with a radio direction-finder gave no definite result. There was no reason to suspect a bushing particularly until it broke down in service. Recurrence of similar interference about a year later resulted in location of the bushing causing it, by a process of sectionalizing. The bushing was removed and cut up; it was a condenser bushing with tinfoil layers on the taper portions at each end, but with no tinfoil layers in the middle portion, in which there was a partial puncture—a blackened hole of perhaps $\frac{1}{16}$ in. diameter—extending about halfway through the paper insulation. As would be expected, the insulation resistance of the bushing gave no indication of this defect. No measurement was made of power factor or capacitance, but it seems improbable that the defect would have affected the capacitance, and if this is so it is difficult to see how the power factor could have been affected.

In a condenser bushing in which the tinfoil layers extend through practically the whole length of the bushing, a breakdown between layers of tinfoil should reduce the insulation resistance and increase the capacitance. As the active and reactive components of current through the insulation would both be increased by such partial failure of a condenser bushing, the power factor would only be changed to a small extent. A bushing made of solid insulation throughout would be differently affected by a partial puncture. In fact, it is difficult to see how either the resistance, the capacitance, or the power factor could be measurably affected by a "pin-hole" extending, say, halfway through the insulation. Similar considerations would apply to the solid portions of an oil-filled bushing.

The two arc-suppression schemes described in the paper can be applied only to systems in which the neutral may safely be raised to normal phase potential. As an alternative to them on a system with the neutral earthed, it might be practicable, in case of a single-phase earth fault, to earth the faulty phase directly at one or more points, through a high-speed single-pole circuit-breaker. On the figures quoted in the paper, the faulty phase would have to be earthed for 12 cycles to prevent the arc from restriking, and if loss of synchronism can be avoided with the normal switching-off and reclosing in not more than 20 cycles a somewhat longer time would perhaps be permissible without loss of synchronism when one phase only was earthed. A relay to act on either excessive current or low voltage on one wire, and a special single-pole circuit-breaker to carry the fault current only for a few seconds, should both be capable of high speed. Such a scheme would have the advantage that it could be applied fairly cheaply as an addition to an existing system of protection in which the circuit-breakers were not of the high-speed type, and in which, to get selectivity, the circuit-breakers at the power station would have to be allowed some seconds to trip. Apparently such apparatus could be arranged to earth and remove the earth on one phase at least once without interfering with the operation of such an existing relay system. There is great reluctance to make a wholesale substitution of high-speed relays and circuit-breakers for existing gear at considerable expense, because it appears to happen persistently that even if relays function correctly according to their principles of operation, the faults themselves are not what they were expected to be. The suggested scheme would require only 3 single-pole high-speed breakers and relays applied to the busbars, and not to each outgoing line.

[The authors' reply to this discussion will be published later.]

MEETING HELD AT WELLINGTON, NEW ZEALAND, 31ST JANUARY, 1938

Mr. J. G. Lancaster: It is the object of electricity supply engineers in New Zealand to give maximum continuity of supply to our four principal centres, especially for their essential services such as transport, street lighting, and hospitals, and to the more important Governmental services such as railway traffic signal

systems, telephone exchanges, and, possibly to a less degree, railway electrification. Another class of load in which continuity is of great importance is the coal-mining industry, where an outage of a few minutes' duration may result in disaster, on account of the stoppage of fans and pumps, unless the men are immediately withdrawn from underground. In these particular cases it is necessary to provide for duplication of generators or generating stations, transmission lines, transformers, and feeders, and to install auto-reclosing gear and all the necessary protective equipment. It is fortunate that the revenue from such loads as a rule justifies expenditure on these precautions.

Many of us here are, however, more interested in the question of the rural undertakings of the country, where we meet an entirely different set of circumstances. We have 108 000 miles of overhead conductors, and 50 % or more of these conductors are operating at 11 000 volts. These lines supply for the greater part small communities and a scattered population with a consumer density as low as 3 per mile of line; the economic factor is therefore of paramount importance. In designing such systems we have to balance carefully the risks involved, the degree of service to be given, and the cost. In spite of these disabilities we get what we contend is reasonable continuity, but this is only made possible by active co-operation between supply authorities and the State Departments (chiefly the Public Works Department, which is the principal generating authority).

As the authors point out, the risk of outages is greatest on overhead lines. We experience such outages, which are mainly earth faults, caused, in the majority of cases, by falling trees. In the interests of public safety the Public Works Department has laid down rigid requirements in the matter of earth leakage.

We aim at selectivity between branch feeders and main feeders of a local-authority system, between such feeders and the departmental substation, and again between the substation and the generating station; and here we have what seems to be a difficult problem. According to the paper, in the main generating stations we should aim at high-speed protection and I take it that this would apply principally to very high-kVA rupture faults resulting from trouble in the generating and transmission portion of the system. On the other hand, in the case of faults occurring on the supply-authority system, the protective equipment in the main generating station must have sufficient time-lag to enable the line immediately affected to clear itself and so to limit the interruption to one small area, and to indicate to the supply engineer within reasonable limits where the fault has occurred. In this connection I suggest that the ratio-balance system outlined in the paper is worthy of careful consideration.

One of the greatest electricity supply problems in New Zealand to-day is that of the inductive interference with communication lines which is produced by an earth fault on the power system. In this connection I am interested to learn of the voltage-injection principle suggested by the authors as a means of reducing the earth current. Would such a method act rapidly enough to satisfy the communication authorities?

Whatever we may do to improve the physical methods of obtaining maximum continuity of supply, our efforts may sometimes fail on account of the human element. I heard recently that provision is contemplated in Britain to guard against violence which might cause disruption in the main supply, and that underground generating stations isolated from any point of contact with the main system are suggested in order to ensure the maintenance of essential services.

Mr. J. Lythgoe: In 1913 I was employed in Christchurch on the layout of the first underground 11 000-volt reticulation. We carried out about 20 miles of underground reticulation on a loop system to our substations, and we never had a shutdown on the system. Our only means of protection was overload relays, with an earth connection in our Armagh Street station. Since then the supply has grown considerably, and high-capacity circuit-breakers have had to be installed to give continuity of supply.

At the present time there are in New Zealand four large centres where the class of apparatus described in the paper is becoming necessary, but in the majority of the distribution districts, such as those operated by Power Boards, it would not be economically sound to install such equipment.

In the development of our supplies we have to face problems of a very particular type. My district includes about 1 000 farms which depend on electric power for doing their work during the milking periods. These periods commence at this time of the year at about 6 a.m. and last till about 9, and in the afternoon start at about 4 and last till about 6.30 p.m. Continuity of supply is therefore very important. With the exception of an interruption caused by a storm, we have had no serious shutdown. On our outgoing lines we have earth-leakage protection, which has given satisfactory service. As the load increases we shall have to take into consideration further protective equipment, and also the question of running additional lines in the loop form to give service should one section of the line become inoperative.

Mr. G. W. Wyles: Conditions in New Zealand and in England are so different, particularly from the economic point of view, that whereas a complete system of protection such as that described in the paper would be fully justified in England, in New Zealand we must be content with less costly forms. With a major installation the cost of the protective system is a comparatively small item, but to provide the same class of protection on a small installation means additional expenditure amounting to a considerable proportion of the total cost.

Mention is made in the paper of a resistance in the neutral connection, but its value is not stated, and I should like further information in regard to this. In New Zealand at the present time such a resistance is limited to 10 ohms. The matter is of considerable interest, particularly in regard to the limitation of voltage-rises due to fault conditions, and the consequent effect on communication circuits.

Comparing the various systems of pilot-wire protection with the use of carrier frequencies over the main power wires, it is apparently assumed that the pilot wires would, generally speaking, be run in cable. I have in mind a reticulation line some 60 miles in length through country

which is subject to violent storms, and it would seem that open wiring for the pilot wires would be quite unsuitable under these conditions. Carrier working over the power line would probably give a more reliable system of protection.

The system of arc-suppression by voltage injection is interesting, and it might reduce the inductive interference with communication circuits which is at present a serious matter when a fault occurs.

Mr. I. R. Robinson: In New Zealand rural reticulation is being successfully carried out at a density of 2–3 consumers per mile. Consumers in such rural areas cannot expect, should not expect, and should not be given the same standard of continuity of supply as the large cities. If, however, they expect it and by agitation demand it and get it, the price of electricity to them will have to be increased. In rural areas the only safeguards available are therefore a high standard of construction and of maintenance. To enable maintenance work to be carried out, pre-arranged shutdowns are useful, and ensure that interruptions do not take place at critical times. So far as a large area in New Zealand is concerned, there is no reason why for an hour or two on Sunday afternoons the power should not be off.

In the Introduction the authors state that the interconnection of generating plants accentuates the need for safeguards. It should be pointed out, however, that the interconnection of generating plants means that there are often alternative routes of supply to a consumer, and to this extent interconnection perhaps lessens the need for safeguards.

The authors state that overhead lines are the most prolific source of fires. Is this statement based on any data derived from analysis of troubles on systems of overhead lines as compared with those of underground cables? It should be pointed out that trouble on high-voltage lines does not usually involve such extensive damage as trouble in generating stations or transformer substations.

Turning now to Section (2)(A), I would mention simplicity of layout as an additional factor which has an influence on the general continuity of supply. If the system of connections is too complicated, in an emergency it becomes difficult for operators to grasp the situation and quickly restore supply.

Referring to Section (2)(B), my experience with ohmmeter tests is such as to give me a little more confidence in them than the authors have. Such tests are not suitable for determining the absolute state of a piece of apparatus but are useful for determining the relative state of two or more pieces of similar apparatus. For example, in the case of a 110-kV oil switch which has six bushings of the same make and the same date of manufacture, tests at the same time on these six bushings will give an idea of their relative state. If these tests are repeated in 6 months' time, it may be possible to detect any changes which are going on. Such methods have enabled us to detect moisture in an oil-filled 110-kV bushing, to detect a faulty pot-head at the end of a single-phase cable, and to detect faulty 110-kV bushings in transformers. As the result of this last test we were able to prevent trouble arising in some 25 others. Power-factor tests are much better, but they require elaborate apparatus, which is somewhat cumbersome for use in the field. We have carried out tests using an ordinary 30-kV oil-immersed testing set on 110-kV bushings, and measuring the amount of leakage current only. This method has led us to take out of service two or three bushings with excessive leakage currents, and which subsequent examination indicated would have given trouble later.

I should like to refer to the value of a general maintenance schedule as a safeguard against interruption. Throughout the Government system in New Zealand practically all insulators above 11 kV are tested every year by means of a "buzz-stick" method, and consequently there are practically no interruptions due to punctured insulators. In all oil-filled apparatus the oil is tested every 6 months; do the authors consider this the best interval at which to make such a test? In connection with such a maintenance schedule there should be a definite system of seeing that the work is done and also for suitably recording the results.

With reference to Section (3), I agree with the authors that the aim of any protective scheme should be to get a fault off the system as quickly as possible, not only to avoid extensive damage to apparatus but also to prevent system instability being set up between large generating stations connected together over long overhead lines. In New Zealand, in the southern portion of the North Island, we have had a few instances of system instability due to faults of long duration. Even at the cost of lengthening relay sections somewhat the time required to disconnect faults should be reduced as much as possible. Thus, with four substations on a line—say, A, B, C, D (B and C being relatively small)—it might be advisable to relay only from A to D.

Many faults on overhead systems are due to external causes (excluding lightning) such as fires under the line, hay-stackers coming in contact with the line, and branches of trees blown against the line. A fault of this nature may change very quickly from an earth fault to a phase-to-phase one, and back again to an earth fault. With the modern tendency to have separate relay systems for earth faults and for phase-to-phase faults, the changing nature of the fault may cause incorrect relay operation.

Busbar protection has had as yet little application in New Zealand, but as time goes on it will have to be considered. Hitherto, busbar protection has consisted of over-current relays on the generators and some form of back-up directional relay protection at the substations. Busbar protection can be more easily applied where the connections are relatively simple.

Turning to Section (4)(A), we have had some experience which indicates the value of low-resistance footings for towers. On the 110-kV line from Waikaremoana to Napier most of the flashovers due to lightning have taken place in one locality where the resistances of the footings are considerably higher than elsewhere.

In considering protection against lightning generally it should be borne in mind that the essential parts of a system are the generators and transformers, and therefore the aim should be to give maximum protection to these even at the expense of perhaps having to face occasionally a total shutdown. Under certain circumstances, arresters may not have the capacity to lower

the voltage sufficiently to give adequate protection to transformers and generators, and under these circumstances some form of spillover gap should also be installed. These gaps will spark-over when the voltage rises above their sparkover value, and will cause a total interruption, but in this way the generators and transformers are saved from being subjected to excess over-voltage. The degree of protection against lightning depends on the ceraunic level of the country. In New Zealand, where this is generally low, it is not necessary to provide as great a degree of protection as may be necessary where the ceraunic level is higher.

I should like to emphasize the value of statistics as a guide to the safeguarding of any system. The analysis which follows gives the results of 5 years on the Government system covering the southern portion of the North Island of New Zealand, and deals with 204 troubles. The system consists of two hydro-electric stations (20 000 kW and 40 000 kW), 582 miles of 110-kV overhead lines, 105 miles of 50-kV lines, 28 miles of 11-kV lines, fourteen 110-kV substations, and three 50-kV substations. A "trouble" is defined as something which causes an interruption, or would have caused an interruption if relays had not operated.

		Percentage	*Number*
Apparatus	11 kV, 50 kV, 110 kV	22	45
Lines	Defects	16	31
	External causes	10	21
Generators		3	7
Lightning		16	33
Operation (mistakes, etc.)		19	38
Sundry, and unknown		14	29
		100	204

Mr. J. H. Lee: In regard to the general question of routine tests on installed switchgear, I should like to refer to the preliminary recommendations made by the Committee appointed by the Electricity Commissioners to consider what precautions should be adopted in switch-rooms to prevent a repetition of such an occurrence as the fire at Bradford generating station. One of these recommendations is that insulation tests should be made at intervals of not more than 3 months on all switchgear; these should be supplemented where possible by power-factor or high-voltage d.c. leakage tests, and by pressure tests at 6-monthly intervals. I should like to know whether the authors agree with this recommendation, and, if not, what their recommendations would be in regard to routine testing.

One point not touched on by previous speakers is the question of ultimate safeguards. When I visited a number of power stations and substations in London in 1936 I was impressed by the elaborate precautions which were being taken in the general layout and construction of the switchgear to minimize fire danger. Important switchboards were subdivided into a number of sections, each entirely separated from the others by fireproof barriers, and in almost every case automatic fire-extinguishing apparatus was installed, including an arrangement for automatically shutting the doors of the switch-room in the event of a fire. We in New Zealand have no need to go as far as that. On the other hand, I do feel that we have not taken sufficient precautions to ensure that a bad fire shall not follow a breakdown.

In indoor switchgear installations it is of primary importance to ensure that any leakage of oil is not free to flow over the whole of the floor of the switch-room. In large installations the space below each circuit-breaker tank could be partitioned off with vertical sills, and independent sumps could be arranged to drain the oil from beneath each circuit-breaker. In addition, much improvement could be effected by filling cable-trenches with such material as sand or pebbles, which would be fire-resisting.

In the case of outdoor installations also, I would stress the fact that large areas of concrete are very undesirable. It is preferable that oil-filled apparatus should be mounted on concrete plinths surrounded by at least 12 in. of rubble, so that in the event of the bursting of a tank the oil would not spread over the whole substation site.

I should be interested to have further information from the authors as to the extent to which busbar protection is being installed in England. As far as I know, no scheme of busbar-zone protection has been installed in New Zealand.

I am interested in the authors' brief reference to impulse-tested apparatus, and I should like to have some indication of the extent to which impulse-tested apparatus is being called for and installed in England.

Mr. D. Jamieson: The authors direct attention to various schemes aimed at restricting, and in some cases eliminating, troubles which develop in electrical apparatus. One of these troubles, and quite an important one, arises in bushings. In the present state of the art it does not seem possible to manufacture bushings which will give 100 % service indefinitely. There are a great variety of causes for failure. I should think the principal cause of defects in manufacture, particularly of high-voltage bushings of the paper-insulated type, is the presence of voids in the paper. Some of the recent literature on the subject indicates that one means of detecting the presence of such voids is to plot a curve of the power factor or watts loss of the bushing against voltage, the objective being to ensure that no sharp change occurs in that curve below the working voltage. If a change does occur, the point is sometimes referred to as the point corresponding to ionization by collision. It has been stated, and seems to be generally agreed, that if that point occurs below the working voltage (in the case of paper-insulated bushings) failure of the bushing will inevitably occur, although perhaps after a period of years. I should like the authors' opinion as to whether it would be reasonable to ask in specifications that all bushings should be subjected to such a test as a condition of acceptance. As to the causes of the failure of bushings in service, the main one when high-voltage bushings were filled with solid compound was the formation of voids in the filling, and some elaborate researches have been carried out in England to determine what changes in temperature and other conditions would give rise to the formation of cracks in bitumen. These were not productive of any useful result, and the next step in the progress of design was to replace a solid compound by a semi-solid compound. Failures

still occur in bushings with semi-solid compound, and these failures can quite generally be attributed to moisture. One of the principal sources of ingress of moisture was the top cap of the bushing, and a good deal of attention has been directed towards obtaining a watertight joint on this cap. It appears to me that the top joint of a bushing should not only be watertight but also airtight, for the reason that paper is hygroscopic and, in the absence of any impregnating treatment, it would absorb moisture from the atmosphere. There is about 14 % of moisture in an average sample of ordinary paper.

The authors mention the use of lightning arresters both on lines and in substations; in order to make a rational selection from the large number of types of arresters available, some criterion must be set down as to the required performance. Can the authors state such a criterion? Many of the protective systems described in the paper make use of pilot wires, and one of the great bugbears of such schemes is failures due to voltages induced in the pilot wires from the power lines associated with them. There appear to be certain circumstances under which the pilots themselves are protected by discharge devices such as lightning arresters, and in many cases the pilots necessarily parallel the power lines at a fairly close separation. Certain types of fault, e.g. an earth fault on the outdoor structure of a substation which is fed from generating stations on either side of it, might normally be expected to produce a discharge in the arresters on the pilot wires at the substation. As the current is being fed in from both sides a discharge is produced in the pilot wires and flows in towards the arrester that has broken down at the substation, with the result that the discharge current in the arrester may be double what it is in an arrester at a remote end of the pilot. There seems to be some doubt as to what the current-carrying capacity of the arrester should be in a case like this. In one particular case some calculations which I made indicated a current of the order of 90 amperes in the earth lead of the arrester; but there is not on the market any arrester for communication-line protection which could be expected to deal with a current of this magnitude. I should like to have the authors' opinion as to what the carrying capacity of an arrester for protecting a pilot wire should be. Also, what is a common rating for such an arrester on a typical system working under severe conditions?

(*Communicated*) I should like to take this opportunity of ventilating the question of the reliability of pilot wires on comparatively long lines.

In New Zealand there are some natural features which are largely absent in European countries: two important ones are earthquakes and extensive and continually-shifting river beds. It is mandatory on all supply authorities here to render an annual return of broken wires. This has been done over a number of years. On each occasion the analysis has shown the principal cause to be falling trees, which account for about 40 % of all failures, while the next principal cause is probably vibration.

Table A

Analysis of Telephone Interruptions, January, 1931, to October, 1935, inclusive*

	Line No. 2 (89 miles)	Line No. 3 (174 miles)	Line No. 4 (240 miles)	Line No. 5 (64 miles)	Total (567 miles)	Percentage total	Remarks
Line faults, vibration breaks ..	13	20	113	—	146	29·05	All on cadmium-copper
Line faults, other causes ..	41	59	35	31	166	32·98	
Dynamic induced voltages ..	2	9	11	—	22	4·38	
Lightning	1	1	2	2	6	1·19	
Operating mistakes	7	10	5	3	25	4·97	
Faulty apparatus	6	9	13	4	32	6·37	
Portables on line	—	2	1	2	5	0·99	
Broken lightning arresters ..	—	4	2	—	6	1·19	
Unknown	11	39	32	13	95	18·88	
Totals ..	81	153	214	55	503	100·00	

* The analysis includes all interruptions which necessitated a line patrol or a post and telegraph call. On the Mangahao-Bunnythorpe section, No. 2 and No. 3 lines are side-circuit and No. 4 line is a phantom circuit, so that a broken wire would generally interrupt at least two circuits and sometimes three. In such cases, they have been repeated on each circuit which they affected.

Bearing in mind the possibility of utilizing the existing private telephone lines associated with the main transmission lines on the southern portion of our North Island system for purposes of synchronizing at substations, central supervisory control, and pilot-wire protective systems, an analysis (see Table A) was made of the causes of failure and interruption so far as these could be determined from the power-station logs over a period of approximately 5 years. One of the principal causes, vibration, has now been practically eliminated by the adoption of dampers, but it will be seen that many general causes remain. The general conclusion could scarcely be avoided that absolute reliance could not be placed upon pilot-wire systems in this region, either for protective systems or for remote-control systems.

Comparison with the reliability of the Post Office lines over the same route has not been made. With the principal exception that the P.O. circuits follow roads, whereas the private lines examined frequently run across

country in farming areas, I should think that the P.O. circuits would be subject to much the same hazards. It is possible that a very high standard of maintenance (which is costly) might bring down the number of failures very considerably, but it appears that certain causes such as falling trees, farming operations, and vandalism, will be operative for many years to come.

Mr. R. S. Maunder: With regard to the question of protecting cables in substations, there are two major risks of serious shutdown here, one from the cables themselves and the other from oil. In Wellington we are giving serious consideration to the idea of removing standard coverings from cables and using asbestos tape, also of filling cable trenches with pebbles. A non-inflammable oil is now available for transformers, voltage-transformer and current-transformer chambers, etc., but the difficulty is that the apparatus requires to be specially designed for it. If this problem is solved the use of non-inflammable oil should become standard practice, and if the price of the new oil is reasonable we shall be glad to use it.

As far as transformers are concerned, the volume of oil becomes serious, especially where the transformers are installed in confined spaces as in some city areas. The solution appears to be drained floors with proper rubble pits of sufficient capacity to take away all oil from transformers. The difficulty is to arrange for these after the transformers have been installed.

Individual busbar protection is too costly to be adopted by New Zealand supply authorities, but consideration has been given to dividing up the Wellington 11-kV system into zones, each with back-up protection in case of busbar faults. It is difficult to provide simple zone back-up protection, and I should like to know whether the authors can tell us of protective systems for groups of substations taken as a unit. On our system the solution seems to be overload and earth-leakage protection with definite time-limits, but it is very difficult to get discrimination and at the same time reasonable stability.

There is need for co-operation between generating authorities and distribution authorities on the question of how far one authority should spend money to avoid causing disturbances to the whole system.

It would be of great help if The Institution could issue, say every 2 years, a summary of major troubles that have occurred on supply systems (without, of course, mentioning names), and an account of the solutions that have been adopted. Such reports could be sectionalized to cover large and small power stations, overhead transmission lines, underground h.t. cables, large substations, and general distribution problems.

Mr. R. A. McLennan: Modern protective systems are very complex, and doubt is sometimes cast on the reliability of the relays embodied in them. In communication work relays are used every day, and the type used for telephone-switching and radio purposes is very reliable and can be left for years without any attention whatsoever. For power purposes I would suggest that instead of designing one heavy-duty relay complete for one particular phase of the work, we should install a suitable pilot relay such as is used for telephone work. This pilot would incorporate any time-lag features, and, with the certainty of action born of long experience, would control an ordinary quick-acting heavy-duty relay suitable for the high currents in the control circuit. Such pilot relays are cheap, definite in action, and easily adjustable. Heavy-duty relays are more difficult to design for definite time-lags than are light-duty relays, one reason for this being the relatively high mechanical mass and the use of pivots instead of springs.

In connection with pilot wires, surely these need not always be run close and parallel to the transmission lines. In many cases they could be run in the ordinary telephone cables rented from telephone supply authorities, their maintenance then being taken as part of the general maintenance of the whole system. Such telephone routing would give a path less likely to be adversely affected by the causes giving rise to the transmission-line failure.

I should like to know whether the authors find that there is any interruption in the operation of carrier protection devices during the time at which the fault is at its worst. In other words, do the transient conditions paralyse the "protection"? In the case of total failure of a transmission line is there sufficient feed across the gap to operate the terminal equipment? There have been cases in ordinary communication work where intelligible signals have been received despite a broken line. Are the requirements for carrier protection more stringent than for telephonic or telegraphic communication?

Mr. F. G. Robson: Until the coming of the British grid I take it that English manufacturers had little opportunity for practical experience in protective schemes for large interconnected systems and open lines at high voltages and power. With the advent of the grid, conditions more akin to those ruling in the Dominions came into existence, giving the English manufacturer opportunities and a demand for proving his equipment and thus making available to the overseas engineers apparatus backed by experience gained in the field. This is evident from the number of protective schemes installed in this country in the past on which foreign protective equipment has been installed on English switchgear, etc., to meet some particular requirement, other than a purely orthodox protective system.

From articles which have appeared in various technical journals I gather that there are definite limitations to several of the systems put forward by the authors. Information on these limitations, and the methods adopted to overcome them in respect of the various types of faults which are liable to develop on the system to which they are applied, would be of interest.

There are cases where it is impossible to put in high-speed protection owing to initial charging and magnetizing currents which necessitate the introduction of some form of time-delay. Any equipment enabling this to be done and yet maintaining correct discrimination so that faults developed in a small section of the system are not communicated back to the main distribution centre, are amongst the most common problems which come up for solution. Any system on which a time-delay is introduced merely for the purpose of overcoming, say, the initial current-rush of a line or transformer installation, and where after the closing of the breaker the time element is cut out and high-speed protection operates, is, in my opinion, useless. With such an arrangement no discrimination can be given between closing the circuit-

breaker on a fault and on normal conditions. It would be of interest to know how far high-speed protection can be applied, and along what lines it has been developed to overcome the difficulty of accurate discrimination in such cases.

Mr. W. B. King (*communicated*): Dealing first with the subject of general safeguards, Section (2)(A), perhaps a little criticism is deserved by manufacturers who, 10 or 12 years ago, stated that switchgear had a certain kVA rupturing capacity, and now advise that this capacity must be reduced enormously, thus necessitating the scrapping of installed switchgear. In any large supply system, the layout should be as simple as possible to avoid operating errors, and also to keep down the cost of the necessary protective relays. With a very complex layout, the number of relays necessary may cause more inconvenience through wrong operation than would be the case in a simple system.

Turning to the question of routine safeguards, Section (2)(B), with a well-designed system, routine testing of all apparatus, and intelligent tabulation of the statistical data thereby obtained, would appear to be the greatest safeguard against interruptions. In the southern portion of the North Island generation and transmission system, for a number of years systematic testing and maintenance have removed dozens of incipient faults which would inevitably have led to interruptions in service. Practically all apparatus is tested at least every 6 months. In this district, although the limitations of the ohmmeter are well recognized, by its aid it has been possible to save at least two 110-kV bushings. By tabulating readings every 6 months it is possible, in certain instances, to tell that insulation is deteriorating. Power-factor testing has not been applied in this district, but recently measurements of the combined capacitance and leakage current of bushings at normal voltage (and, again, tabulation) have enabled us to save at least two bushings.

The whole question of the system of protection to be employed is an economic one, in which the cost of insurance must be considered in relation to the cost of interruption and the consequent inconvenience to consumers, and perhaps the consequent damage to apparatus.

As regards ultimate safeguards, Section (2)(D), from experience in this district it would seem that if generating and transformer equipment is fully safeguarded, most other apparatus can be done without, and service quickly restored after any emergency. This was shown by the severe earthquake which occurred in Napier in 1931; a very severe gale in 1935; and also in the case of substation fires. In the case of the Napier earthquake the transformers were put out of service, but as soon as others were provided supply was restored to essential services. In other cases, transformers were intact and service was restored within a few hours.

No scheme for long-distance transmission of power in New Zealand could at present afford to make use of any system of pilot-wire protection, for two reasons: (1) The cost is prohibitive in relation to the amount of power transmitted. (2) The reliability of the pilot wires would not be so good as that of the transmission system (evidence of this is provided by the lower reliability of the telephone lines paralleling the transmission lines). Underground cables for pilot wires are out of the question.

Most of the busbar faults which have occurred in this district have been caused by 110-kV or 50-kV bushing failures due to the entrance of moisture. In several instances, the condenser portion of the bushing stood up to service after the fault had cleared itself. In the absence of a certain quantitative test for these bushings, with a proper system of 110-kV busbar protection there might, owing to leakage, be many operations of protective relays before the trouble could be located, which might be only when the bushing definitely failed.

Low values of footing resistance for towers appear, from experience, to be necessary to ensure freedom from flashover of insulators during lightning storms. Failing a low footing-resistance, some form of counterpoise would appear to be necessary. Lightning is not of sufficient importance to be specially guarded against with earth wires on the main transmission system, but it would appear to be good practice to install earth wires for 1–2 miles on each side of substations, and to grade the line insulators down.

Table B

TROUBLES OF MANGAHAO-WAIKAREMOANA SYSTEM—8 YEARS ENDING 31ST MARCH, 1937

Trouble on:—	Percentage of total
11-kV apparatus	7·7 (chiefly cable-boxes)
110-kV and 50-kV apparatus	13·8 (chiefly bushings)
110-kV lines, defects	8·6 } *
110-kV lines, external causes	8·6 }
50-kV lines	6·4
Operations	18·4
Lightning	12·3
Relays	4·3
Others	19·9
	100·0

* Although 110-kV lines give only 17·2 % of troubles, the duration of interruptions on these lines is about 35 % of the total interruption time.

Automatic reclosing of 11-kV breakers is becoming standard practice in New Zealand for radiating feeders. Have the authors any information regarding automatic reclosing on 110-kV or high-voltage lines connecting two generating stations? Petersen coils are not used in this country as it is customary for the neutral to be solidly earthed.

Transient faults at normal voltage on 110-kV lines in New Zealand have been traced to many causes, such as the following (see Table B: "110-kV lines, external causes"): (*a*) Birds evacuating down insulator strings. (*b*) Salt deposits on insulators. (*c*) Fires under lines. (*d*) Accidental contact with hay-stackers and other farm machinery.

With regard to bushings for 50-kV and 110-kV apparatus, many failures have occurred in condenser-type bushings, practically all of which were apparently due to water

entering at the top cap; only one was due to failure of the condenser portion. One failure of an oil-filled bushing has been experienced, the outer porcelain being cracked in this case. I should like to have the authors' views on the relative merits of oil-filled and condenser-type bushings, as American practice appears to favour the oil-filled type while British practice prefers the condenser type.

[The authors' reply to this discussion will be published later.]

DISCUSSION ON "THE LOCALIZATION OF EXPOSED BREAKS IN SUBMARINE CABLES"*

Instructor Lieut.-Commander D. K. McCleery (*communicated*): The use of de and di which occurs half way down the right-hand column of page 410 will be depressing to the mathematicians, since these quantities are certainly not infinitesimals.

With reference to Schaefer's method, I have shown elsewhere† that this follows at once from the assumption of the validity of the Kennelly inverse square-root law, conditionally upon the two currents not being very widely different. It is interesting to notice that the author quotes Schaefer as advising that the ratio should not exceed 3 to 1 "owing to divergence of the law." Doubtless it afforded Mr. Schaefer almost endless pleasure and amusement to carry out the numerous experiments upon the results of which he based his "law," but I feel that his claim to a particular "law" may, in view of my researches, be allowed to lapse into oblivion.

Unfortunately my paper did not appear until quite recently, although the work described in it is some 6 or 7 years old, and Mr. Storey seems to have been unaware of it.

Mr. A. L. Storey (*in reply*): Though I saw Lieut.-Commander McCleery's paper shortly after it was published, my paper had then passed finally out of my hands, and thus it was not possible to make any reference to this welcome addition to the literature concerning the subject.

With regard to Schaefer's method, though the claim to a particular law may be allowed to lapse, the association of Schaefer's name with a method that has proved, and still is, so often useful will not pass away.

* Paper by Mr. A. L. Storey (see page 409).
† *Electrician*, 1939, vol. 122, p. 625.

THE BENEVOLENT FUND

41ST ANNUAL GENERAL MEETING, 11TH MAY, 1939

Dr. A. P. M. Fleming, C.B.E., D.Eng., M.Sc., President, took the chair at 5.30 p.m.

The notice convening the meeting was taken as read. The minutes of the 40th Annual General Meeting held on the 12th May, 1938, were also taken as read and were confirmed and signed.

The Report of the Committee of Management (see below), and the Statement of Accounts for the year 1938 (see page 762), were presented and, on the motion of the chairman, seconded by Mr. L. W. Phillips, were unanimously adopted.

On the motion of the Chairman it was resolved that Mr. A. J. Attfield, F.C.A., be elected Honorary Auditor for the year 1939.

The Chairman reported the constitution of the Committee of Management for the year 1938-39 (see vol. 84, page 152).

The meeting then terminated.

REPORT OF THE COMMITTEE OF MANAGEMENT OF THE BENEVOLENT FUND FOR 1938

Capital

The Capital Account stood on the 31st December, 1938, at £23 863 2s. 2d., which is invested.

Receipts

The Income for 1938 from dividends, interest, and annual subscriptions, was as follows:—

	£	s.	d.
Dividends and Interest ..	1 080	8	10
2 260 Annual Subscriptions ..	1 184	0	0
	£2 264	8	10

In addition to the foregoing, the Fund benefited during the year by the following subscriptions and donations:—

Donations

	£	s.	d.
Mersey and North Wales (Liverpool) Centre:			
Golf Tournament ..	106	15	0
Surplus on Dinner, Collections, etc. ..	5	14	5
North-Western Centre, Golf Tournament ..	106	0	0
Surplus from I.E.E. Summer Meeting ..	100	0	0
North Midland Centre:			
Golf Tournament ..	40	18	11
Collections at Meetings ..	14	10	0
Electrical Engineers' Ball at Harrogate	25	0	0
Western Centre and West Wales Sub-Centre	72	0	10
Anonymous ..	43	11	8
"The Twenty-Five Club" ..	26	5	0
Staff of English Electric Co., and other friends (in memory of the late Mr. P. Constant) ..	26	0	0
Sheffield Sub-Centre, Electrical Engineers' Ball ..	21	0	0
Incorporated Municipal Electrical Association ..	10	10	0
Incorporated Municipal Electrical Association, Golf Tournament ..	12	0	0
London Students' Section, Surplus from Summer Tours, 1937 and 1938 ..	18	14	11
North-Western Centre, Manchester Engineers' Ball ..	15	15	0
Scottish Centre:			
Golf Tournament ..	5	15	0
Excursion to Taymouth Castle ..	3	11	0
National Register of Electrical Installation Contractors ..	10	10	0
Henley's Telegraph Works Co., Ltd. ..	25	0	0
General Electric Co., Ltd. ..	10	10	0
Messrs. Kennedy and Donkin ..	10	10	0
Messrs. Merz and McLellan ..	10	10	0
R. W. Paul ..	500	0	0
H. Marryat ..	151	14	5
Lord Hirst of Witton ..	30	0	0
Dr. R. Bown ..	15	15	0
T. S. Watney ..	10	16	0
G. W. Smart ..	10	10	0
A. C. O'Bryen ..	10	0	0
F. Gill ..	7	7	0
H. W. Kolle ..	6	6	0
Anonymous ..	5	5	0
A. G. Bruty ..	5	5	0
A. C. Eborall ..	5	5	0
S. Evershed ..	5	5	0
V. E. Faning ..	5	5	0
Dr. A. P. M. Fleming ..	5	5	0
K. Fraser ..	5	5	0
E. P. Grimsdick ..	5	5	0
G. H. Nisbett ..	5	5	0
F. C. Raphael ..	5	5	0
P. Rosling ..	5	5	0
Sir John Snell ..	5	5	0
H. T. Young ..	5	5	0
L. C. F. Bellamy ..	5	0	0
J. M. Donaldson ..	5	0	0
J. M. Kennedy ..	5	0	0
R. G. Kilburne ..	5	0	0
H. E. Morrow ..	5	0	0
K. A. Scott-Moncrieff ..	5	0	0
E. A. Short ..	5	0	0
N. S. Tennant ..	5	0	0
and 3 550 donations of under £5 ..	1 310	11	11
	£2 882	7	1

Legacy

The Fund also benefited to the extent of £100 under the will of the late Mr. William Guy-Pell, Member.

Electrical Engineers' Ball

The annual Electrical Engineers' Ball, held on the 11th February, 1938, realized a surplus of £201 11s. 6d., which was handed to the Fund.

Income

The total income from all sources for 1938 was £5 448 7s. 5d., which compares with £4 338 9s. 3d. for 1937.

Grants

Applications for assistance were made by or on behalf of 81 persons during 1938, and the Committee after due consideration made grants in 73 of the cases. In assisting these persons the Fund also provided for the necessities of 64 dependants.

The total amount of the grants was £3 826 5s. 6d., which compares with £4 434 3s. 7d., for 1937.

Donors and Subscribers

Lists of the names of donors and subscribers are issued to members of The Institution annually, and the Committee of Management desire to tender their cordial thanks to all the contributors.

During 1937 the amount expended in grants exceeded the income of the Fund from all sources, including dividends, by over £100.

With a view to improving the financial position of the Fund the President, Dr. A. P. M. Fleming, made a special appeal to members to contribute in larger numbers, and it is gratifying to note that at the end of 1938 the financial position was greatly improved, the surplus of income over expenditure being £1 560 3s. 10d. A special donation of £500 was received from Mr. R. W. Paul, and another of £151 14s. 5d. from Mr. H. Marryat, in addition to the amounts from local functions mentioned above. The Council earnestly hope that all members of The Institution will give the Fund their continued support.

Refund of Income Tax

The Fund is able, under the provisions of the Finance Act, 1922, to recover income tax on annual subscriptions, provided the subscribing member signs a deed of covenant to give a fixed amount per annum for a minimum period of 7 years. A number of contributors of large amounts have already agreed to subscribe under this arrangement, and if any other member wishes to subscribe under the scheme the Honorary Secretary of the Fund will be pleased to supply him with the necessary form and particulars.

Wilde Fund

The Capital Account stood on the 31st December, 1938, at £3 049 16s. 2d., all of which is invested and brings in an annual income of about £104.

The balance standing to the credit of the Income Account (from which, under the Trust Deed, only full Members and their dependants can benefit) on the same date was £91 9s. 9d.

Grants amounting to £35 were made from this Fund during the year.

The income of this fund is administered by the Committee of Management of the Benevolent Fund, and its Accounts are published in the *Journal*.

THE BENEVOLENT FUND OF THE INSTITUTION OF ELECTRICAL ENGINEERS.

INCOME AND EXPENDITURE ACCOUNT FOR THE YEAR 1938.

Dr. EXPENDITURE.

Year ended 31 Dec., 1937. £ s. d.		£ s. d.
4,434 3 7	To Grants	3,826 5 6
31 10 3	,, Printing, Stationery, Postage, etc.	61 18 1
	,, Unexpended Balance carried to Balance Sheet..	1,560 3 10
£4,465 13 10		£5,448 7 5

INCOME. **Cr.**

Year ended 31 Dec., 1937. £ s. d.		£ s. d.	£ s. d.
1,012 15 10	By Dividends and Interest		1,080 8 10
244 4 1	,, London Electrical Engineers' Ball		201 11 6
	,, Donations of £5 and over:—		
	Mersey and North Wales (Liverpool) Centre Golf Tournament	106 15 0	
	North-Western Centre Golf Tournament	106 0 0	
	North Midland Centre Golf Tournament	40 18 11	
	Incorporated Municipal Electrical Association, Golf Tournament	12 0 0	
	Scottish Centre Golf Tournament	5 15 0	
	North Midland Electrical Engineers' Ball	25 0 0	
	North-Western Centre, Manchester Engineers' Ball ..	15 15 0	
	Sheffield Sub-Centre Engineers' Ball	21 0 0	
686 10 4	Other donations	1,238 11 3	1,571 15 2
1,236 14 0	,, Donations under £5		1,310 11 11
1,108 5 0	,, Annual Subscriptions		1,184 0 0
50 0 0	,, Legacy		100 0 0
(Deficit) 127 4 7			
£4,465 13 10			£5,448 7 5

BALANCE SHEET, 31st DECEMBER, 1938.

Dr. LIABILITIES.

		£ s. d.
To Capital Account:—		
As per last Balance Sheet		23,863 2 2
,, Income and Expenditure Account:—		
As per last Balance Sheet	£3,381 7 7	
Unexpended Balance in 1938	1,560 3 10	
		4,941 11 5
,, Grants authorized but not yet disbursed		3 15 0
,, Sundry Creditors		10 6 8
,, Subscriptions and Donations received in advance		14 11 0
		£28,833 6 3

ASSETS. **Cr.**

		£ s. d.
By Investments (Capital), at cost:—		
£961 7s. 7d. Cape of Good Hope 3% Stock (1933–43)		950 0 0
£420 London and North Eastern Railway 4% First Preference Stock		503 18 3
£450 London, Midland and Scottish Railway 4% Debenture Stock		551 0 9
£750 East Indian Railway 3½% Debenture Stock		737 18 0
£300 London, Midland and Scottish Railway 4% Guaranteed Stock		333 11 6
£500 New Zealand 3½% Stock (1940)		486 18 6
£500 Canada 3½% Stock (1930–50)		478 16 0
£5,800 3½% War Stock		5,783 6 1
£350 New South Wales 4% Stock (1942–62)		336 18 6
£2,580 4% Funding Stock (1960–90)		2,123 15 6
£3,295 3½% Conversion Stock (1961)		2,512 11 10
£450 Commonwealth of Australia 5% Stock (1945–75)		438 16 0
£450 Tynemouth Corporation 5% Stock (1947–57)		457 7 3
£950 Agricultural Mortgage Corporation 5% Debenture Stock (1959–89)		988 5 6
£1,000 Southern Railway 5% Redeemable Guaranteed Preference Stock (1957)		1,028 7 0
£1,000 Southern Railway 5% Guaranteed Preference Stock		1,000 3 0
£1,000 Hastings Corporation 5% Stock (1947–67)		980 2 0
£800 London Passenger Transport Board 5% "A" Stock (1985–2023)		808 2 6
£700 Ayr County Council 5% Stock (1947–57)		733 7 0
£1,000 Commonwealth of Australia 4% Stock (1955–70)		1,012 13 0
£900 South Essex Waterworks Co. Perpetual Debenture 4% Stock		1,014 4 6
£650 London County Council 2¾% Consolidated Stock (1960–70)		602 19 6
(Market value 31st December, 1938, £25,115 13s. 10d.)		£23,863 2 2
,, Investments (Income) at cost:—		
£1,050 Newcastle and Gateshead Water Co. 5% Consolidated Preference Stock	£1,513 14 6	
£1,050 London County Council 2¾% Consolidated Stock (1960–70)	977 15 9	
£1,000 3% Funding Stock (1959–69)	1,033 5 6	
£1,000 4½% Conversion Stock (1940–44)	1,053 18 0	
(Market value 31st December, 1938, £4,269 5s. od.)		4,578 13 9
,, Sundry Debtors		28 8 5
,, Cash:—		
At Bank	£359 16 1	
In hands of Honorary Secretary	3 5 10	
		363 1 11
		£28,833 6 3

I have audited the above Balance Sheet and Income and Expenditure Account with the Books and Vouchers and certify them to be correct, and have verified the Investments with Certificates from Banks.

ARTHUR J. ATTFIELD, F.C.A.
Honorary Auditor.

29th April, 1939.

PROCEEDINGS OF THE INSTITUTION

945TH ORDINARY MEETING, 30TH MARCH, 1939

Dr. A. P. M. Fleming, C.B.E., M.Sc., President, took the chair at 6 p.m.

The minutes of the Ordinary Meeting held on the 9th March, 1939, were taken as read and were confirmed and signed.

A list of candidates for election and transfer, approved by the Council for ballot, was taken as read and was ordered to be suspended in the Hall.

A paper by Messrs. J. W. Beauchamp, Member, and R. Kauffmann, Companion, entitled "State Regulation of Electricity Supply Tariffs: Recent German Legislation compared with British Tendencies" (see page 569), was read and discussed.

A vote of thanks to the authors, moved by the President, was carried with acclamation.

946TH ORDINARY MEETING, 13TH APRIL, 1939

Dr. A. P. M. Fleming, C.B.E., M.Sc., President, took the chair at 6 p.m.

The minutes of the Ordinary Meeting held on the 30th March, 1939, were taken as read and were confirmed and signed.

The President announced that during the month of March 540 donations and subscriptions to the Benevolent Fund had been received, amounting to £218. A vote of thanks was accorded to the donors.

Messrs. F. E. Rowland and W. E. Pannett were appointed scrutineers of the ballot for the election and transfer of members and, at the end of the meeting, the President reported that the members whose names appeared on the lists (see vol. 84, page 769) had been duly elected and transferred.

A paper by Messrs. T. E. Allibone, D.Sc., Ph.D., Member, F. E. Bancroft, and G. S. Innes, B.Sc., Associate Member, entitled "The St. Bartholomew's Hospital X-Ray Tube for One Million Volts" (see page 657), was read and discussed. The paper was illustrated by a cinematograph film.

A vote of thanks to the authors, moved by the President, was carried with acclamation.

947TH ORDINARY MEETING, 27TH APRIL, 1939

Dr. A. P. M. Fleming, C.B.E., M.Sc., President, took the chair at 6 p.m.

The minutes of the Ordinary Meeting held on the 13th April, 1939, were taken as read and were confirmed and signed.

A list of candidates for election and transfer, approved by the Council for ballot, was taken as read and was ordered to be suspended in the Hall.

Messrs. F. de B. Hart, F. C. Knowles, and G. F. Shotter, were appointed scrutineers of the ballot for the election of new Members of Council.

Prof. P. M. S. Blackett, M.A., F.R.S., then delivered the Thirtieth Kelvin Lecture, entitled "Cosmic Rays" (see page 681).

Dr. C. C. Paterson: We have listened to Prof. Blackett's discourse with fascination and with admiration: with fascination because the subject has led us as engineers along paths which we do not often tread but the interest and the significance of which appeal very strongly to us, and with admiration because as an exponent of any subject Prof. Blackett has few to equal him in lucidity and virility. The engineer has the habit of asking what is the use of a thing which is brought to his notice, but the day has passed when any apology is needed for expending time and effort on an inquiry the incentive of which is simple curiosity. Nevertheless, there is one known practical use of cosmic rays, for it is doubtful whether any of our discharge lamps would strike up were it not that the minute ionization of cosmic rays trigger off the effect of ionization by collision between the electrons in the tubes, so enabling the luminous discharge to build up. We welcome this closer acquaintance with the mesatron, which produces such valuable results in our discharge tubes, and has evidently been serving us well for very many years in modest anonymity. I propose that a very hearty vote of thanks be accorded to Prof. Blackett for his Lecture.

Prof. C. L. Fortescue: It is appropriate to consider for a moment why we appreciate so much Prof. Blackett's interesting lecture. I think the reason is that this is an experimental investigation which depends upon observations, much in the same way that our own ordinary engineering work depends upon direct experiment. When an engineer is drawing up a specification he must rely on objective fact and cannot indulge in anything of a speculative nature. The physicist, on the other hand, sometimes gives the impression of indulging in speculation, but in this lecture we have had a description of an experimental technique which has given certain information, and of the careful observation and intellectual efforts which have been enlisted to interpret the experiments. These efforts are very similar to those which we ourselves are called upon to make in our ordinary engineering work, and that is why the lecture makes such a very direct appeal to us. I have very great pleasure, therefore, in seconding the vote of thanks.

The vote of thanks to Prof. Blackett was then carried with acclamation.

67TH ANNUAL GENERAL MEETING, 11TH MAY, 1939

Dr. A. P. M. Fleming, C.B.E., M.Sc., President, took the chair at 6 p.m.

The notice convening the meeting was taken as read.

The minutes of the Ordinary Meeting held on the 27th April, 1939, were also taken as read and were confirmed and signed.

Messrs. W. H. Dennis and S. B. Warder were appointed scrutineers of the ballot for the election and transfer of members, and, at the end of the meeting, the President reported that the members whose names appeared on the list (see vol. 84, page 771) had been duly elected and transferred.

The Premiums (see vol. 84, page 768) awarded by the Council for papers during the session were then announced by the President.

The President next summarized the Annual Report of the Council (see vol. 84, page 726) and moved its adoption. The motion was seconded by **Mr. F. C. Knowles.**

Mr. L. W. Phillips referred to several items in the Report, especially the question of an Education Section of The Institution. He was of the opinion that such a Section might also deal with economics and management, which subjects he thought many members considered were not receiving sufficient attention.

The President in reply said that Mr. Phillips's comments would be brought before the appropriate committees.

The motion for the adoption of the Annual Report was then put to the meeting and was carried unanimously.

Mr. W. McClelland (*Hon. Treasurer*) in submitting the Annual Accounts, said: " The total expenditure for the year amounts to £50 353, against £48 255 last year, an increase of £2 098. This increase is accounted for, in large measure, by £1 600 increase in the cost of the *Journal.* This is due to more copies being printed for the larger number of members, to a larger publication owing to the larger number of papers, and to an increase in the costs of printing and paper.

" There is one matter to which I might call the attention of members of The Institution, and that is to the fact that expenditure has risen considerably over a number of years. This is due partly to the general economic conditions which have prevailed, with the upward trend in prices, and to many commitments in recent years, such as scholarships, increased grants to outside bodies, the *Students' Quarterly Journal*, and the inauguration of the Wireless, Meter and Instrument, and Transmission Sections. The total income for 1938 (as shown on page 739, vol. 84), is made up of £6 167 from interest and dividends on our investments which have been accumulated in the past, and of £50 118 from members' subscriptions and minor sources, making a total of £56 285, as against a total income last year of £53 926, an increase of £2 359. The expenditure, therefore, for 1938 is such that it has absorbed all our income from subscriptions and minor sources, and in order to cover normal expenditure it has been necessary to encroach to the extent of £224 on the income from interest and dividends. The encroachment is small, but the Finance Committee and the Council are watching very closely the continued increase in expenditure relative to the income from subscriptions, and, without adversely affecting progress or the usefulness and the general service of The Institution, are endeavouring to keep normal expenditure within the income, excluding that from interest and dividends. I thought that general statement—relatively unimportant —might be of interest to the members.

" If you refer to page 738 (vol. 84), Revenue Account, you will find that the balance carried to the Balance Sheet is £7 067, as against £6 810 in 1937. Turning to the Balance Sheet (page 740) you will see that the net surplus for the year is £5 943. This compares with £5 671 in the previous year. The total Assets are shown (on page 741) as £231 988 and the Liabilities (page 740) as £11 700, thus leaving a surplus of Assets over Liabilities of £220 288. Of this surplus, you will see that £135 562 is invested in trustee securities, this figure being the actual cost; the market value of these investments at the 31st December, 1938, was £149 904, i.e. £14 342 above their cost, whilst on the first day of the present month their market value was £143 109, which is still £7 547 in excess of their book value, in spite of the very depressed state of the markets consequent upon the disturbed international situation.

" With those figures before you and with the auditors' certificate which appears at the bottom of page 741, I am sure you will all agree that the finances of The Institution continue to be very satisfactory. Before I formally put the resolution to you I should like to thank our Secretary, Mr. Rowell, and his staff for their assistance to me at all times in connection with these Accounts; and, as Hon. Treasurer, I should also like to pay my tribute to Mr. Rowell for his great financial achievement in building up during his secretaryship what amounts to a capital reserve of well over £150 000. May he live long to enjoy his well-earned retirement."

The motion for the adoption of the Accounts was seconded by **Dr. C. C. Paterson, O.B.E.,** and was carried unanimously.

The President then moved " That the best thanks of The Institution be accorded to the following officers for their valuable services during the past year: (*a*) the Hon. Secretaries of the Local Centres; (*b*) the Local Hon. Secretaries abroad; and (*c*) the Hon. Treasurer, Mr. W. McClelland, C.B., O.B.E.

The resolution was seconded by **Mr. F. A. Orchard** and was carried with acclamation.

Mr. D. J. Bolton, M.Sc.(Eng.), then moved " That Messrs. Allen, Attfield and Co. be appointed auditors for the year 1939–40." The resolution was seconded by **Mr. F. Jervis Smith** and was carried unanimously.

The meeting then terminated.

948TH ORDINARY MEETING, 11TH MAY, 1939

Dr. A. P. M. Fleming, C.B.E., M.Sc., President, took the chair at 6.58 p.m., immediately after the conclusion of the Annual General Meeting.

He announced that, during the month of April, 328 donations and subscriptions to the Benevolent Fund had been received, amounting to £148. A vote of thanks was accorded to the donors.

Captain B. S. Cohen, O.B.E., Member, then delivered the Fifteenth Faraday Lecture, entitled "The Long-Distance Telephone Call: a Triumph of Engineering and Co-operation."

A vote of thanks to the lecturer, moved by the President, was carried with acclamation.

INSTITUTION NOTES

INDEX TO JOURNAL

Any member who proposes to bind the current volume of the *Journal* and would like to have an extra copy of the Index for filing apart from the bound volume of the *Journal*, can obtain an additional copy on application to the Secretary.

LIST OF MEMBERS

The new List of Members, corrected to the 1st September, 1939, has now been published. Any member wishing to receive a copy should apply to the Secretary.

"THE HISTORY OF THE INSTITUTION"

An order form for copies of "The History of The Institution of Electrical Engineers," by Mr. Rollo Appleyard, was circulated to every member on the 26th October. Members whose orders were received by the 15th November (15th January, 1940, for members overseas) have been able to obtain copies at the specially reduced price of 7s. 6d. Any member who has not applied for a copy can still obtain one at the special price of 12s. 6d. (the price to the public is 18s. 6d. per copy).

MILITARY SERVICE

Steps have been taken to ensure that members of all classes of the leading engineering and professional Institutions, when called up for military service, either as militiamen or for compulsory war service, will be posted to Units in which their services would be best employed in the national interest and, in the case of Graduates and Students, to units in which the training will be of use to them on returning to civilian work.

The authorities have given special instructions to "interviewing" officers that a note should be taken of anyone who comes before them who is a member of any such Institution, so that "posting" officers will know how the member's services can be used to the best advantage.

Members of any class, therefore, should specifically mention that they are members when supplying particulars of their qualifications to "interviewing" officers and should indicate then their desire to join one of the technical Units, such as the Royal Engineers, the Royal Corps of Signals, the Royal Army Ordnance Corps, Searchlight Units, etc.

In order that members will be able to leave with the "interviewing" officer some documentary evidence of membership, a letter stating his class of membership will be supplied to any member on application being made by him to the Secretary of The Institution.

MEMBERS FROM OVERSEAS

The Secretary would be glad if members coming home from overseas would inform him whenever possible in advance of their visit, stating their address in this country even if they do not wish a change of address recorded in the Institution Register.

The object of this request is to enable him to advise members visiting this country of the various meetings and functions of The Institution and its Local Centres and, when occasion arises, to put them into touch with other members.

The Secretary would also be pleased to receive visits from overseas members and to assist them in any way possible during their stay in the United Kingdom.

OVERSEAS MEMBERS AND THE INSTITUTION

During the period 1st July to 30th November, 1939, the following members from overseas called at The Institution and signed the "Attendance Register of Overseas Members":—

Attard, J. (*Malta*).
Bardens, A.T.B. (*Bermuda*).
Bennett, A. P. M. (*Athens*).
Bennett, D. P. (*Colombo*).
Blofeld, T. G. (*Tarkwa*).
Eckersley, T. (*Calcutta*).
Gellion, F. J. (*Macao*).
Gregory, H. J. (*Kuala Lipis*).
Griffith, R. M. (*Sydney, N.S.W.*).
Ingham, F. (*Nairobi*).
Keay, A. L. (*Khodaung*).
Kaul, P. N. (*Jamalpur*).
Kinsman, C. (*Durban*).
Lewis, N. N. (*Abadan*).
Lye, D. H. C. (*Ipoh*).
McIntyre. A. N. (*Calcutta*).
Manton, W. J. W. (*Shanghai*).
Miles, W. (*Shanghai*).
Miller, W. L. E. (*Shanghai*).
Morgan, D. L. (*Kuala Lumpur*).
Mumford, W. B. R. (*Calcutta*).
Ogden, Captain G. W., B.A. (*Khartoum*).
Pheasant, J. W. A. (*Dacca*).
Plioushtch, T. (*Istanbul*).
Sharpley, Prof. F. W., F.R.S.E. (*Dhanbaid*).
Shiva, A. Q., B.Sc. (*Abadan*).
Urquhart, S. R. (*Singapore*).
Whyte, W. L. (*Kampala*).

ACTIVITIES OF THE INSTITUTION

A circular setting out The Institution's programme for the second half of the Session is enclosed with this issue of the *Journal* to every member.

PARSONS MEMORIAL LECTURE

The Parsons Memorial Lecture for this year was to have been delivered under the aegis of The Institution of Civil Engineers, by Dr. H. L. Guy, F.R.S., his subject being "Some Researches on Steam-Turbine Nozzle-Efficiency." The Lecture will now be published in the December number of the *Journal* of that Institution, and a limited supply of copies of the Lecture will shortly be available to members of the I.E.E., application for which should be made to the Secretary, I.E.E., Savoy Place, Victoria Embankment, W.C.2.

PROCEEDINGS OF THE TRANSMISSION SECTION

31st Meeting of the Transmission Section, 18th January, 1939

Mr. S. R. Siviour, Chairman of the Section, took the chair at 6 p.m.

The minutes of the meeting held on the 14th December, 1938, were taken as read and were confirmed and signed.

A paper by Messrs, T. R. Scott, B.Sc., Member, and R. C. Mildner, M.Sc.(Eng.), Associate Member, entitled "Long-Period Ageing Tests on Solid-Type Cables" (see page 67), was read and discussed.

A vote of thanks to the authors, moved by the Chairman, was carried with acclamation.

32nd Meeting of the Transmission Section, 15th February, 1939

Mr. S. R. Siviour, Chairman of the Section, took the chair at 6 p.m.

The minutes of the meeting held on the 18th January, 1939, were taken as read and were confirmed and signed.

A paper by Prof. W. J. John, B.Sc.(Eng.), Member, and C. H. W. Clark, Ph.D., Graduate, entitled "Testing of Transmission-Line Insulators under Deposit Conditions" (see page 590), was read and discussed.

A vote of thanks to the authors, moved by the Chairman, was carried with acclamation.

33rd Meeting of the Transmission Section, 8th March, 1939

(Joint Meeting with the Chemical Engineering Group of the Society of Chemical Industry.)

Mr. S. R. Siviour, Chairman of the Section, took the chair at 6 p.m.

The minutes of the meeting held on the 15th February, 1939, were taken as read and were confirmed and signed.

Mr. Siviour welcomed the Chairman, Mr. W. Russell, and the members of the Chemical Engineering Group of the Society of Chemical Industry present at the meeting.

A paper by Messrs. W. G. Radley, Ph.D.(Eng.), Member, and C. E. Richards entitled "The Corrosion of Underground Cables" (see page 685), was read and discussed.

A vote of thanks to the authors, moved by the Chairman, was carried with acclamation.

34th Meeting of the Transmission Section, 12th April, 1939

Mr. S. R. Siviour, Chairman of the Section, took the chair at 6 p.m.

The minutes of the meeting held on the 8th March, 1939, were taken as read and were confirmed and signed.

The Chairman announced that the following members had been nominated to fill the vacancies which would occur on the Committee on the 30th September, 1939:—

Chairman: Mr. F. W. Purse.

Vice-Chairman: Mr. H. J. Allcock, M.Sc.

Ordinary Members of Committee: Messrs. R. E. G. Horley, S. W. Melsom, F. H. Sharpe, B.Sc., and J. A. Sumner.

In the event of a ballot for the new Committee being required, Messrs. L. M. Jockel and A. M. Perry, B.Sc. (Eng.), were appointed scrutineers.

A paper by Messrs. E. W. W. Double, B.Sc.(Eng.), and W. D. Tuck, B.Sc.(Eng.), Associate Members, entitled "Vibration of Overhead Line Conductors," was read and discussed.

A vote of thanks to the authors, moved by the Chairman, was carried with acclamation.

35th Meeting of the Transmission Section, 10th May, 1939

Mr. S. R. Siviour, Chairman of the Section, took the chair at 6 p.m.

The minutes of the meeting held on the 12th April, 1939, were taken as read and were confirmed and signed.

A paper by Mr. D. J. Bolton, M.Sc.(Eng.), Member, entitled "Superimposed Control Applications, with special reference to Tariffs and Load-Levelling," was read and discussed.

A vote of thanks to the author, moved by the Chairman, was carried with acclamation.

ACCESSIONS TO THE REFERENCE LIBRARY

[Note.—The books cannot be purchased at The Institution; the names of the publishers and the prices are given only for the convenience of members; (*) denotes that the book is also in the Lending Library.

Aitken, W. Who invented the telephone? Sm. 8vo. xii + 196 pp. (London: Blackie and Son, Ltd., 1939.) 5*s*. (*)

Keal, H. M., and Leonard, C. J. Mathematics for electrical students: algebra, geometry, trigonometry, and applied electrical problems. 2nd ed. vii + 225 pp. (New York: John Wiley and Sons, Inc.; London: Chapman and Hall, Ltd., 1938.) 8*s*. (*)

Keenan, J. H., and Keyes, F. G. Thermodynamic properties of steam; including data for the liquid and solid phases. 8vo. 89 pp. (New York: John Wiley & Sons, Inc.; London: Chapman & Hall, Ltd., 1936.) 13*s*. 6*d*. (*)

Klemperer, O. Electron optics. 8vo. x + 107 pp. (Cambridge: University Press, 1939.) 6*s*. (*)

Krahenbuehl, J. O., *M.S.*, and Faucett, M. A., *M.S.* Circuits and machines in electrical engineering. 8vo. vii + 691 pp. (New York: John Wiley and Sons, Inc.; London: Chapman and Hall, Ltd., 1939.) 22*s*. 6*d*. (*)

Kron, G. Tensor analysis of networks. 8vo. xxiv + 635 pp. (New York: John Wiley and Sons,

Inc.; London: Chapman and Hall, Ltd., 1939.) 37*s*. 6*d*. (*)

McIlwain, K., and Brainerd, J. G. High-frequency alternating currents. 2nd ed. 8vo. xv + 530 pp. (New York: John Wiley and Sons, Inc.; London: Chapman and Hall, Ltd., 1939.) 30*s*. (*)

MacInnes, D. A. The principles of electrochemistry. 8vo. 478 pp. (New York: Reinhold Publishing Corporation, 1939.) 30*s*. (*)

McLachlan, N. W., *D.Sc.(Eng.)*. Complex variable and operational calculus with technical applications. 8vo. xi + 355 pp. (Cambridge: University Press, 1939.) 25*s*. (*)

Magnusson, C. E., *M.S.*, *Ph.D.* Alternating currents. 5th ed. 8vo. xiii + 721 pp. (New York; London: McGraw-Hill Publishing Co., Ltd., 1939.) 30*s*. (*)

Marchant, E. W., *D.Sc.* An introduction to electrical engineering. 8vo. xii + 297 pp. (London: Methuen and Co., Ltd., 1939.) 12*s*. 6*d*. (*)

Meyer, E., *Dr.* Electro-acoustics. With a foreword by C. L. Fortescue. 8vo. xi + 117 pp. (London: G. Bell and Sons, Ltd., 1939.) 10*s*. (*)

Monk, S. G., *M.Sc.(Eng.)*. Induction motors. 8vo. viii + 126 pp. London: Blackie and Son, Ltd., 1939.) 5*s*. (*)

Moon, A. R., *M.A.*, and Golding, G. F., *M.A.* The King's English for commercial students. sm. 8vo. x + 182 pp. (London: Longmans, Green and Co., 1939.) 2*s*. 3*d*.

Moyer, J. A., and Fittz, R. U. Air conditioning. 2nd ed. 8vo. x + 455 pp. (New York; London: McGraw-Hill Book Co., Inc., 1938.) 23*s*. (*)

Myers, L. M. Electron optics, theoretical and practical. 8vo. xviii + 618 pp. (London: Chapman and Hall, Ltd., 1939.) 42*s*. (*)

Neukirchen, J., *Dr.* Carbon brushes. A presentation of the variables connected with current collection and commutation. Translated by E. I. Shobert. 8vo. 166 pp. (St. Marys, Pa., U.S.A.: Stackpole Carbon Co., 1937.) $3.000. (*)

Newnes, George, Ltd. The meter engineer's pocket book. sm. 8vo. 231 pp. (London: George Newnes, Ltd., 1939.) 3*s*. 6*d*.

Ohm, G. S. George Simon Ohm als Lehrer und Forscher in Köln, 1817 bis 1826. Festchrift zur 150. Wiederkehr seines Geburtstages. Herausgegeben vom Kölnischen Geschichtsverein im Verbindung mit der Universität und dem Staatlichen Driekönigs-Gymnasium in Köln. (Köln: Kommissionsverlag J. P. Bachem, 1939.) *RM*.6.

Okabe, K. Magnetron-oscillations of ultra-short wavelengths and electron-oscillations in general. sm. 8vo. 57 pp. (Osaka: Shokendo, 1937.) 5*s*.

Olson, H. F., *Ph.D.*, and Massa, F., *M.Sc.* Applied acoustics. 2nd ed. 8vo. xviii + 494 pp. Philadelphia: P. Blakiston's Son and Co., Inc.; London: Constable and Co., Ltd.) 25*s*. (*)

Phillips, R. S. Electric lifts. A manual on the current practice in the installation, working, and maintenance of lifts. 8vo. x + 293 pp. (London: Sir Isaac Pitman and Sons, Ltd., 1939.) 20*s*. (*)

Procter, W. S. Questions and answers in telegraphy and telephony. sm. 8vo. vii + 205 pp. (London: Sir Isaac Pitman and Sons, Ltd., 1938.) 6*s*. (*)

Radley, J. A., *M.Sc.*, and Grant, J., *Ph.D.*, *M.Sc.* Fluorescence analysis in ultra-violet light. 3rd ed. Being vol. 7 of a series of monographs on applied chemistry. Under the editorship of E. H. Tripp. 8vo. xvi + 424 pp. (London: Chapman and Hall, Ltd., 1939.) 22*s*. 6*d*. (*)

Raskop, F. Isolierlacke deren Eigenschaften und Anwendung in der Elektrotechnik insbesondere im Elektromaschinen- und Transformatorenbau. (Berlin: M. Krayn, 1938.) *RM*.8.50.

Reed, H. R., *M.S.*, and Corcoran, G. F., *M.S.* Electrical engineering experiments; theory and practice. 8vo. xii + 500 pp. (New York: John Wiley and Sons, Inc.; London: Chapman and Hall, Ltd., 1939.) 22*s*. 6*d*. (*)

Reich, H. J., *Ph.D.* Theory and applications of electron tubes. 8vo. xviii + 670 pp. (New York; London: McGraw-Hill Publishing Co., Ltd., 1939.) 30*s*. (*)

Reyner, J. H. Testing television sets. 8vo. viii + 128 pp. (London: Chapman and Hall, Ltd., 1938.) 9*s*. 6*d*. (*)

Rissik, H. The fundamental theory of arc convertors. A theoretical study of the principles underlying the design and operation of arc convertor circuits. (London: Chapman and Hall, Ltd., 1939.) 18*s*. (*)

Rogers, P. L. Power-factor economics. 8vo. vii + 143 pp. (New York: John Wiley and Sons, Inc.; London: Chapman and Hall, Ltd., 1939.) 12*s*. 6d. (*)

Rose, T. G. Higher control. 3rd ed. With a foreword by A. H. Pollen. 8vo. x + 277 pp. London: Sir Isaac Pitman and Sons, Ltd., 1938.) 12*s*. 6*d*. (*)

Rubber Technology Conference. Proceedings of the R.T.C. held under the auspices of the Institution of the Rubber Industry, May 23–25, 1938, London. Edited by T. R. Dawson and J. R. Scott. la. 8vo. xxxviii + 1137 pp. (Cambridge: W. Heffer and Sons, Ltd., 1938.) 42*s*.

Russell, A., *D.Sc.*, *LL.D.*, *F.R.S.* Lord Kelvin. 8vo. vi + 163 pp. (London: Blackie and Son, Ltd., 1938.) 5*s*. (*)

Schallreuter, W. L., *Ph.D.* Neon tube practice. 2nd ed. 8vo. 255 pp. (London: Blandford Press, Ltd., 1939.) 10*s*. 6*d*. (*)

Schilling, W., *Dr.-Ing.* Die Gleichrichterschaltungen: ihre Berechnung und Arbeitsweise. 8vo. 279 pp. (München: R. Oldenbourg, 1938.) *RM*.17.50.

Shorter, L. R. Introduction to vector analysis. With many fully worked examples and some applications to dynamics and physics. sm. 8vo. xiv + 356 pp. (London: Macmillan and Co., Ltd., 1931.) 8*s*. 6d. (*)

Siegel, G., *Dr.Ing.*, and Nissel, H. La Tarification de l'énergie électrique. Prix de revient de l'énergie électrique, etablissement et application des tarifs. Traduit par A. Alexander-Katz. 8vo. xii + 338 pp. (Zurich: L'Electrodiffusion, 1938.) 15*s*.

Sims, J. W. Electrical installations. A handbook of theory and practice for technical students, apprentices to electrical and building trades, and electricians. sm. 8vo. viii + 191 pp. (London: John Murray, 1938.) 6*s*. (*)

Smith, *Eng. Capt.*, E. C., *O.B.E.*, *R.N.* A short history of naval and marine engineering. With a foreword by Major P. J. Cowan. 8vo. xix + 376 pp. (Cambridge: University Press [for Babcock and Wilcox, Ltd.], 1937.) 18*s*.

ARTHUR FRANCIS TURNOUR ATCHISON, B.Sc., was born in London in 1881, and was educated at Glenalmond and the Mason College, Birmingham. He obtained the diploma and became an Associate of the College, and in 1903, after the establishment of Birmingham University, was awarded the B.Sc. degree for a thesis. After working for a time with an electrical firm he was appointed demonstrator in electrotechnology at the Royal Engineering College, Coopers Hill, taking sole charge of the department on the retirement of the professor. When that college was closed, in 1906, he spent some time with an English firm and with the General Electric Co. in Berlin. He passed next into the education service of the Egyptian Government and had charge of the equipment and starting of technical schools. Later he took service with the Ministry of the Interior and eventually became Director-General of the Section of Municipalities and Local Commissions in Cairo, an office in which he had the inspection and supervision of the electrical installations of these municipalities. After a service of 18 years he retired in 1923, but continued to reside in Cairo. The papers published by him related chiefly to alternating-current transformers and the behaviour of alternators under load. During his retirement he was able to devote much of his time to music, his chief hobby. He had been in poor health for over a year, and on his last journey to England had to be left in hospital at Genoa where he died on the 25th June, 1939. His collection of scientific and technical books he left to the University of Egypt. He was elected a Student of the Institution in 1900, an Associate in 1902, an Associate Member in 1909, and a Member in 1916. W. W. W.

LLEWELYN BIRCHALL ATKINSON died on the 9th August, 1939, at the age of 75. To most his death was unexpected, and to all it was hard to realize that another great bulwark of The Institution and friend of all who had contact with him had passed away.

Born in 1865, the son of a civil engineer engaged in railway work in many parts of the world, he early became acquainted with engineering matters. He was educated at Merchant Taylors' School on the modern side, and when he left he gained an Exhibition at St. Thomas's Hospital. The electrical engineering profession nearly lost him, but, fortunately, he decided not to take up the Exhibition but to devote his attention to engineering. He attended the Cowper Street Schools in 1880 under Prof. Ayrton before the Finsbury Technical College was built, and in the following year gained a first prize and silver medal in the City and Guilds Examination in electrical technology. In 1885 he secured the Jelf Medal, two Telford Medals, and Associateship in the engineering section of King's College, London, and, incidentally, in 1926 he was elected a Fellow of his College. In 1885 he was apprenticed at the Airèdale works of Messrs. Kitson and Co., Leeds, and the next year was articled to Goolden and Trotter of London. It was in 1886 also that he took out his first patent for a dynamo brush built in such a way as to prevent sparking. In the following year he was very busy on the application of electricity to mining, for which he took out many patents and concerning which he read several papers. He can, indeed, be counted as one of the early and successful pioneers of electric coal-cutting machinery.

In 1888 he became a partner in Messrs. W. T. Goolden and Co., and 5 years later when that company was amalgamated with Messrs. Easton and Anderson he became a director of the new company and held that position until 1897. In 1900 he was associated with the founding of the Trafford Power and Light Supply Co., of which he was managing director and continued a director for nearly 20 years until the company was acquired by the Stretford Council. In 1903, and for nearly 17 years, he was a director of Messrs. W. T. Glover and Co. In 1916 he was appointed secretary of the Cable Makers' Association on the death of Mr. A. Howard. Later he became the first Director of the Cable Makers' Association, a responsiblity which he so ably filled for a great number of years, and in February, 1936, he was appointed advisory Director to the C.M.A., a position which he held until his death. Before these official duties began, however, he held the office of Chairman of the C.M.A. for the year 1913.

He was elected a Member of The Institution in 1900, became a Member of Council in 1917, Vice-President two years later, and was President in 1920–21. The year of his presidency was an outstanding one in the history of The Institution, because in August, 1921, the Royal Charter was granted. He was made an Honorary Member in 1933, an honour which was indeed well merited. He joined the Model General Conditions Committee in July 1917, became Chairman in April, 1920. and held that position until he resigned in May, 1939, He was appointed a member of the Wiring Regulations Committee during the session 1917–18. He became Vice-Chairman in 1923, and in January, 1925, was appointed Chairman. He resigned the Chairmanship in December, 1928, but continued to serve on the Committee until his death. He was Faraday Lecturer for the 1928–29 Session. He took part in a great many discussions and always contributed interesting and helpful criticisms. His last contribution to his long list of splendid work was the address entitled "Institution Recollections" which he delivered at the Conversazione of Overseas Members on the 13th June, 1939, only a few weeks before his death.

In addition to his Institution activities he was Chairman of the Joint Industrial Council for the cable-making industry from the date of its inception until his death, in which position he obtained the goodwill of both sides. His work on the General Council and Executive Com-

mittee of the National Physical Laboratory, as a member of the Council of the Royal Society of Arts, Vice President of the B.E.A.M.A., Past-President and Past-Chairman of Council of the Electrical Research Association, a member of the Council of the E.D.A., a member of the Council of the Telegraph Development Association, and finally a member of the Electrical Industry Committee and sub-committees of the British Standards Institution, were evidence of his interests other than purely technical ones.

It is interesting to note that in 1923 he read a paper on economics. He took the keenest interest in farming, especially in the feeding and rearing of poultry and pigs, and in this respect he read a paper before the Royal Society of Arts on incubation. He was an expert carpenter with a unique collection of tools and in recent years undertook to panel his hall, which, at his death, was all but completed. He was a great lover of his garden and he always tried to plan large splashes of colour. He was one of the early pioneers of cycling and rode a "Penny-farthing" in the curious uniform of that day, and he included amongst his exploits an adventure that covered as much as 130 miles in 2 days. He was an enthusiast in the early days of photography and—again using his scientific knowledge—collected a valuable number of instruments relating to weather conditions, and with their aid he kept his records very faithfully.

He was also a member of many of the non-technical societies connected with the electrical industry. His material successes, however, had been guided and governed by what he was himself—by the man. Those who knew him, and especially those who were his intimate friends, realized well why he had attained eminence in his profession and secured a warm corner in the hearts of those who met him: it was his broad and kindly outlook on life and work and particularly his attitude towards other people, whose views he considered without losing the focal point at which he himself was aiming. This gift, for instance, on the Joint Industrial Council for the cable-making industry, had endeared him to the labour side just as much as to the employers' side, and consequently he had welded that Council into a very homogeneous unit. It should be recorded that when, under the constitution of the Council, it was the turn of the trade unions to appoint a Chairman they always appointed Mr. Atkinson, and thus he held that honoured position, as has already been said, from the inception of the Council until his death. Coupled with these qualities was his very patient mind which was always seeking a middle way acceptable to all parties and exploring with almost uncanny wisdom every opportunity of an honourable way out of a difficulty, even though the opening might appear to be very small; and because of his chairmanship, conferences which seemed doomed to break up have, on very many occasions, been successfully concluded.

In 1928 his colleagues of the Cable Makers' Association honoured him by presenting his portrait in oils by Mr. George Harcourt, R.A., to The Institution as a mark of their great respect.

The Institution has lost not only an honoured member but a great worker for its best ideals, and its members a very loyal and warm-hearted friend.

He married, in 1894, Nelly Scott, who survives him with their five chidren. E. L.

SYDNEY CHARLES BARTHOLOMEW, M.B.E., died on the 30th June, 1939, and thereby The Institution lost a widely known and very popular engineer whose interests brought him into touch with a very wide circle. He was born in 1873 and was educated at the Naval School at Greenwich, but eye trouble, which was to continue at intervals throughout his life, led to his giving up his intended career in favour of the Central Telegraph Office. In 1900 he was transferred to the Engineering Department of the Post Office and very early in his career he specialized in the subject of interference between power and telecommunication systems. This included a study of the risks of physical contact, electromagnetic, electrostatic, and resistive coupling between parallel lines, and of the corrosion of underground pipe systems by stray currents in the earth. His work often involved research and he was an indefatigable reader of American and other foreign literature on these subjects.

On the formation of the Comité Consultatif International des Lignes Téléphoniques à Grande Distance (C.C.I.F). in 1924, he took a leading part on the appropriate committees. The Commission Mixte Internationale (C.M.I.) was formed a few years later with the object of carrying out experimental work on problems involving the close co-operation of power and telephone engineers. He took a leading part in the formation of this Commission and in formulating its early programmes of research, and was elected President Rapporteur of some of the sub-committees to which the various studies were apportioned. Notwithstanding his devoted championship of the interests of communication circuits where affected by power systems, his unfailing good humour and happy disposition made him many good friends everywhere among representatives of other interests. In 1920 he became the Post Office representative on an I.E.E. Committee set up to advise the Electricity Commissioners on Regulations governing Overhead Power Lines and later upon Regulations for securing the Safety of the Public.

He joined The Institution in 1919 as an Associate Member and was elected a Member in 1921. In 1924 he was awarded the Webber Premium for his paper on "Power Circuit Interference with Telegraphs and Telephones." He also received three medals from the Institution of Post Office Electrical Engineers for papers on the same subject. He was awarded the M.B.E. in 1932. P. J. R.

COLONEL DARWIN BATES, T.D., J.P., D.L., for 37 years works manager of the British Insulated Cables, Ltd., Prescot, died at Huyton, on the 17th December, 1938, at the age of 71. He played a prominent part in the company's growth and was responsible for many improvements which led to the expansion of the works. At the age of seventeen he entered the Silvertown Rubber Co. in London as an apprentice electrical engineer. Later he joined the City of London Electric Lighting Co., and in 1896 he took a position with the British Insulated Cables Co., as it was then known. In

those days the firm was in its infancy, employing a few hundred men in one shop. His technical and organizing abilities soon made their mark, and the company began to expand. When he retired in 1933 the company was giving employment to thousands.

He had a distinguished military career. When the Territorial Force was formed he transferred to this from the old Volunteers and served with the 5th South Lancashire Regiment as second in command until the Great War, when he was promoted to the rank of colonel with instructions to form a second line. After training the men he went out to France with them in February, 1917, being then over 50 years of age. Shortly afterwards he was recalled to England and continued to do other military work in connection with the Herefordshire Regiment before he returned to civil duties. From 1921 to 1928 he was Honorary Colonel of the 55th West Lancashire Divisional Signals. In October, 1928, he retired from the South-West Lancashire Territorial Army Association.

He was a Justice of the Peace, sitting on the Prescot bench, and a Deputy Lieutenant for the county. For several years he was president of the Huyton Golf Club. He was elected an Associate of The Institution in 1892 and became a Member in 1898. B. W.

ERNEST EUSTACE BENHAM was born on the 22nd November, 1873, and died on the 9th June, 1939. He was educated at Bromley High School and the City of London School. From 1891 to 1894 he was a pupil with the Brush Electrical Engineering Co., also attending technical classes. In 1895 he took a special evening course at Finsbury Technical College, and in 1899 went to University College, London, for a special day course. From 1894 to 1897 he held the position of assistant engineer and draughtsman to the Brush Co., and from there went to Berlin as assistant in the Union Elektricitäts Gesellschaft, being engaged on electric tramway construction. In 1899 he joined the firm of Dick, Kerr and Co., where he was in charge of tramway construction contracts. He left this firm in 1900 to take up the position of assistant engineer to Macartney McElroy and Co., and was engaged in similar work. From 1902 to 1906 he acted as assistant engineer to Messrs. Merz and McLellan, and at the end of this period he took a similar position with the Cleveland and Durham Electric Power Co. He relinquished this post in 1908, when he became 1st assistant electrical engineer, and later electrical engineer, in Admiralty service. He retired in 1934 with the rank of Superintending Electrical Engineer. During the latter period of his service with the Admiralty he was in charge of the electrical departments at Gibraltar, Devonport, and Hong Kong Dockyards. He was elected a Student of The Institution in 1894, an Associate in 1897, an Associate Member in 1902, and a Member in 1923.

J. S. P.

HERBERT HENRY BERRY, chairman and managing director of Berry's Electric (1928) Ltd., who died on the 17th March, 1939, was born in 1873. He was educated at University College School and at the Finsbury Technical College under the late Silvanus P. Thompson. He served his apprenticeship with Siemens Brothers, Ltd., at Woolwich, whom he joined in 1889. In 1895 he started in business on his own account at Queen Victoria Street, London. The factory at Birmingham was founded in 1900 and 5 years later the title of the company was changed to Berry, Skinner and Co. The business was formed into a private company in 1918, and the present public company was registered in 1928.

Mr. Berry had over 100 patents in various electrical devices, and was the original inventor of safety-first medium-pressure ironclad switchgear in 1904. His name will, however, be most prominently associated with his invention of the "Magicoal" electric fire, for which letters patent were granted in 1916. The application of fluorescence in connection with electric fires was another fruitful idea.

He took an early interest in electrical industrial organization, and was a member of the Council of the National Electrical Manufacturers' Association from its inception in 1903 until its incorporation in the British Electrical and Allied Manufacturers' Association in 1911. In 1930 he was elected to the Council of the latter Association and was an active and valuable member up to the time of his death. An enthusiastic believer in exhibitions, he was prominent in the organization of the Electrical Exhibitions at Olympia in 1905 and 1911, and in the development of the Electrical Section of the British Industries Fair at Birmingham.

He joined The Institution as a Student in 1891, and was elected an Associate in 1894, an Associate Member in 1899, and a Member in 1908. For many years he served on the Wiring Regulations Committee. J. J. C.

ALFRED SOUTHERLAND BLACKMAN was born at Cheltenham on the 22nd March, 1870, and received his education at a private school at Oxford. From 1887 to 1891 he was apprenticed at the Chelmsford works of Messrs. Crompton and Co., and then served for a time in the London drawing office of the firm. His next position, to which he was appointed in 1892, was that of assistant engineer to the Hove Electric Lighting Co. While at Hove he had charge of the testing work and the maintenance of the mains, and was also responsible during the heavy-load shift for the running of the generating plant. He was appointed city electrical engineer at Aberdeen in 1895, and in 1898 became borough electrical engineer and general manager at Poplar, where he designed and laid down the electricity supply works. From Poplar he went in 1903 to Bradford, where as city electrical engineer he was responsible for the adoption of the 3-phase system of supply. He left Bradford in 1907 to become borough electrical engineer and general manager at Sunderland, a position which he held for 27 years. He retired in December, 1934, and died at Surbiton on the 8th January, 1939. He was elected a Member of The Institution in 1898.

PROFESSOR ANDRÉ BLONDEL died on the 15th November, 1938, at the age of 75. Within a few years of leaving the École Polytechnique and the École Nationale des Ponts et Chaussées he fell a victim to partial paralysis, which virtually kept him to his room for the rest of his life, with the result that all the experimental work which is due to him was necessarily carried out by

others working under his direction. He followed their investigations closely, and endeared himself to them all by his affability and cordiality.

In his career as an engineer in the service of the State he was identified with the Department of Lighthouses and Buoys, and it was to the problems which he encountered in that connection that all his research activities were directed. He was also professor of electrical engineering at the École Nationale des Ponts et Chaussées, where his studies of the theoretical side of his subject led him to evolve the numerous diagrams for electrical machines and lines with which his name is associated.

To give only a few examples, his studies of lighthouses led him to introduce the conception of luminous flux and to elucidate many problems of physiological optics, particularly in regard to the perception of ultra-violet light and to chromophotometry. The electric arcs used in lighthouses were the basis not only of his studies of arc phenomena but also of the invention of the soft-iron bifilar oscillograph. In this connection he was the first to propose in 1901 the oscillographic analysis of sounds and speech. His researches into the problem of the supply of current to lighthouse arcs also led him to investigate the running of alternators in parallel, and he then established the two-reaction theory (direct and transverse) of synchronous machines.

He was a pioneer of wireless telegraphy, establishing communication in 1907 over a distance of 100 km. between la Rochelle and the workshop in the cellars beneath sea-level at the Rochebonne lighthouse. As a result of this work he made very important contributions to the development of the various systems of radio beacons.

He was a man of many intellectual interests and wide general culture. His natural modesty remained unaffected by the honours which were conferred upon him, both in France and in many other countries. He became a member of the Académie des Sciences in 1913, and was awarded the Kelvin Medal in 1929 and the Faraday Medal in 1937.

His interest in research work was fully maintained up to the time of his death, which occurred shortly after he had embarked upon an investigation dealing with underwater sound signals.

He was elected an Honorary Member of The Institution in 1920.

P. M. J. A.

STANLEY BRIGHT who died on the 23rd November, 1938, served as a pupil in the works of Messrs Crompton and Co., from October, 1883, to December, 1886, during which period he received as thorough training in electrical engineering as was possible at that time. He then became Inspector of Electric Light to the East and West India Dock Co., and was in charge of the electric lighting plant at Tilbury Dock, which was then one of the most extensive installations existing, covering an area of 300 acres. In that connection he was responsible for the successful working out of new problems of electric distribution and the transmission of power. On the formation of the London and India Docks Joint Committee in 1889, which controlled the London and St. Katherine, the East and West India, the Royal Victoria and Albert, and the Tilbury Docks, he was placed in charge of all electrical plant and machinery within those areas and carried out the design and reconstruction of several of the earlier installations. He also designed and laid down an entirely new installation on the low-voltage 3-wire system at the Royal Albert Dock. He continued as electrical engineer under the London and India Docks Co. formed in 1900, and held this post continuously after the inception of the Port of London Authority in 1909 until his retirement on medical grounds on the 31st December, 1922, at the early age of 57. In addition to the work already mentioned he was engaged in his later years as consultant by several well-known firms in London.

He enjoyed a very active career, particularly between 1909 and the date of his retirement, as the extensive works of improvement carried out by the Port of London Authority in modernizing the docks and their equipment provided him with opportunities for the exercise of his wide professional knowledge, and the success which attended the many schemes with which he was connected forms a lasting tribute to the vision, enthusiasm, and ability, of a worthy member of The Institution, of which he was elected a Member in 1895.

W. H. V.

WILLIAM ANDERSON BROWN who died on the 13th February, 1939, will be known as one of the pioneers of electricity distribution. He was born in Glasgow in 1871. Here he acquired a knowledge of electricity and was able to accept in 1887 a position on the staff of the newly formed London Electric Supply Corporation, which at that time was building the now historic generating station at Deptford in accordance with the plans of the late Dr. S. Z. de Ferranti. After working at Deptford during its construction, he was transferred to the mains department in Adelphi Arches, where he was responsible for laying and maintaining a large section of the high-voltage, medium-voltage, and low-voltage (10 000 V, 2 400 V, and 100 V) mains.

This nearly unique experience at that early date led to his appointment as mains engineer and superintendent to the first of the municipal electricity undertakings, St. Pancras Vestry, now a Borough Council, where under the late Mr. Sydney Baynes he tested and laid nearly every system of underground mains then available for direct-current 3-wire distribution, to which high-voltage 3-phase substations were eventually added.

Having become recognized as one of the most experienced and competent authorities on underground mains, he was approached by several cable manufacturing concerns, and in 1915 joined the Pirelli General Manufacturing Co., and in 1928 was appointed district manager in Scotland for Callender's Cable and Construction Co. It was during this period, while living in Glasgow, that he was struck down by a serious illness. His impaired health made it necessary to give up his work in Glasgow and return to London, where he took up less arduous duties in connection with Messrs. Lighting, Heating, and Traction Supplies, Ltd., which work he carried on to the day of his death.

His chief characteristic was his knowledge of human nature and his great capacity for managing men. The many hundreds who worked under him learnt to appre-

ciate his kindly nature and sterling qualities and, with those who were privileged to become his friends, will mourn the loss of one they both loved and respected. He was elected an Associate Member of The Institution in 1909, and became a Member in 1912. H. T. H.

SIR THOMAS OCTAVIUS CALLENDER, who died on the 2nd December, 1938, was born in Glasgow in April, 1855, and was educated at Greenock, in London, and later at Boulogne-sur-Mer. He was in France at the outbreak of the Franco-Prussian War; and on leaving that country he devoted the next few years to what later became one of his most absorbing interests—extensive foreign travel. In connection with his father's asphalt paving business, he visited Rumania during the re-paving of the city of Jhassy; and later spent some time in Russia, where the illumination of St. Petersburg Opera House by Jablochkoff candles made a great impression on him, and undoubtedly strengthened his natural electrical bent.

In 1877 he joined his father in business, and when, in 1882, Callender's Bitumen Telegraph and Waterproof Co. was formed, he was appointed manager and devoted all his energies to the development of cables insulated with vulcanized bitumen—the invention of his father—and to a method of laying these solid in asphalt. Within the next few years the Callender "solid system" attracted widespread attention and was being extensively used, not only in England but also on the Continent. Throughout these early developments the tremendous driving force and energy which were his outstanding characteristics found full scope. In 1896 he was elected managing director of the company, a position he held for 42 years.

His travels had endowed him with a keen appreciation of the value of overseas markets, and under his direction the name of Callender became familiar in Africa and India, in China, Egypt, and South America, in Australia and New Zealand. India he visited seven times; he travelled in North, South, and West Africa; and on one occasion penetrated into the Arabian Desert in connection with the installation of electric light by the Sultan Lahej. No detail was too small to escape his scrutiny; no project too great to daunt his spirit. To the end, his grasp of all the ramifications of his company's business was phenomenal, and his memory was exceptional. His was no case of "a prophet not without honour save in his own country." He was known and well-liked throughout the length and breadth of Great Britain. A director of four other cable companies and of three large power companies, it was yet one of his proudest boasts that one engineer of a small municipality bought his cables for 40 years because he once heard him speak and trusted him. Every man in his vast organization regarded him not only with respect and admiration but with a sort of personal affection, and the knighthood conferred on him in 1918 was a source of pride and satisfaction to every man in his service.

His membership of The Institution dated from 1893, when he was elected a Member, and he served on the Council from 1903 to 1906. In 1921 he was President of the Electrical Industries Benevolent Association (then the Electrical Trades' Benevolent Institution) in whose work he took a personal interest from its inception.

His last years were troubled with ill-health, and the loss of his wife the year before his own death was a great grief to him; but he remained indomitably at work to the end, and death, when it came, did but round off quietly a full and useful life. His passing removes from us one more of the dwindling band of pioneers of the early eighties, but his name will always remain an honoured one in the profession he adorned. His enduring monument is the tradition he established, which lives on in those who were proud to serve under him.

P. V. H.

JOSEPH BERNARD CLARKE was born on the 16th December, 1873, and died on the 10th January, 1939. He was educated at Wolverhampton and later attended classes at Finsbury Technical College and Manchester College of Technology. He was for 2 years in the workshops of the Electrical Construction Co. at Wolverhampton and then went for 2 years as improver in the works of the Royal Electric Co. of Montreal. In April, 1899, he was appointed chief engineer to the Kidderminster and District Electric Light and Power Co., and in 1903 chief engineer to the Stourbridge Urban District Council, advising the Council on the design and negotiations for the public electricity supply. From 1905 to 1908 he was employed by the Bristol Corporation and also studied structural design at Bristol University. From 1908 to 1911 he was with the Northampton Electric Light and Power Co. as assistant engineer and introduced the use of reinforced concrete for the Bridge Street generating station. He then went to America and held appointments with the New Haven and Hartford Railroad Co., the West Pennsylvania Electric Power Co. of Pittsburgh, and Messrs. Stone and Webster of Boston. From 1916 to 1920 he was engaged on Admiralty work on paravanes, as department manager with Messrs. Bulpitt and Sons, Birmingham. After a short period in business as an electrical contractor he was, in April, 1922, appointed chief constructional engineer in the St. Pancras Electricity Department and remained in the employ of the Corporation for 11 years, during which period he was responsible for the design and construction of many important extensions, including the Arlington Road automatic substation. On resigning in 1933 he set up in practice as a consulting engineer and from 1936 until the time of his death was connected with Messrs. Rendel, Palmer, and Tritton. He was elected an Associate Member of The Institution in 1902, and a Member in 1930. D. B.-W.

A. E. R. COLLETTE, who was born on the 25th June, 1857, and died on the 3rd June, 1939, entered the Netherlands Postal, Telegraph, and Telephone Service in 1879. In 1899 he succeeded his father as Engineer-in-Chief of the State Telegraphs, which title was changed in 1917 to that of Engineer-in-Chief and Director of the State Telegraphs and Telephones. In recognition of his outstanding work during his 44 years of service, an Order was twice conferred upon him by Queen Wilhelmina. His greatest achievement was his contribu-

tion to the development of telephony and radio communication by stimulating these branches of traffic in the Netherlands. That his interest and knowledge were versatile is evident from the fact that although as an engineer his task was to discover and to promote new technical possibilities, at the same time he drafted the telegraph and telephone laws.

He was a man of character, his judgment was sound, and his decision firm. He never lacked courage to accept responsibility. Towards the outer world he always backed up the management, even on those occasions when he had criticized it in private. Being a man of great independence and moral courage, he often expressed the view that regulations were made to be broken in certain circumstances. Grown up with the service he was personally acquainted with many of those working with him, always being ready to promote their personal interests next to those of the service. In the hall of the radio transmitting-station at Kootwijk a memorial tablet associates his name with that building, which was erected under his supervision. Likewise his name is indelibly printed on the mind of his fellow-workers. He was elected a Foreign Member of The Institution in 1896, and became a Member in 1911. He served as Local Honorary Secretary for Holland from 1896 until his death. H. J. B.

JAMES FREDERICK HEWETT COLYER was born on the 27th May, 1889, and died on the 19th January, 1939. During the period 1895–1905 he was educated at Long's Private School (Cosham), Roan's School (Greenwich), and Dulwich College; and he also attended evening classes at the Regent Street Polytechnic until 1910. On leaving school he joined W. T. Henley's Telegraph Works Co., first in the drawing office and later as a junior in the contract department. In 1910 he was sent to Barbados and in 1914–15 to Shanghai, in control of contract work for the company. Contracts which he undertook in recent years in the capacity of contract manager included some of the largest installations carried out by the Company, both in this country and abroad. His happy flair for smoothing away difficulties both technical and personal gained for him a wide circle of friends among power transmission engineers. He was a director of the Antrim Electricity Supply Co., and in more recent years he had extended his activities to general civil engineering work, in which capacity he was a director of the Holborn Construction Co. He was elected an Associate Member of The Institution in 1919, and became a Member in 1936. P. D.

PROFESSOR WILLIAM CRAMP, D.Sc., was born in Coventry on the 8th January, 1876, and died at Llandudno on the 20th April, 1939. He was educated at King Henry Eighth School, Coventry, and was apprenticed to the firm of Messrs. Rotherham and Sons, at Coventry. During his apprenticeship he attended evening classes at the Technical School, Coventry, and in 1897 went to Messrs. Ferranti Ltd., at Hollinwood, where he continued his studies at the Manchester College of Technology and at the Whitworth College, Manchester. It was there that he first established his reputation as a student of electrical engineering.

In 1901, Prof. Ayrton appointed him Lecturer in Electrical Design at the Central Technical College, South Kensington, where his thoroughness and clarity of expression soon made him one of the most valued members of the staff of the Electrical Engineering Department. It was here also that he began the series of experimental researches which continued to the end of his life. It was at Prof. Ayrton's house that he first met Miss Hartog, a niece of Sir Philip Hartog, whom he married in 1902. In 1906 he joined the Board of Messrs. Henry Simon and Co., of Manchester, where he had a wide experience in designing plant of all kinds and in equipping the many factories with which this firm was concerned. At the same time he gave lectures during the evening at the Manchester College of Technology and later joined Mr. Julius Frith in practice as a consulting engineer.

While in Manchester he became prominently connected with the work of the North-Western Centre of The Institution, of which he was elected Chairman in 1912. His Address on "Higher Education, some Views of a Teacher Employer," was recognized as a masterly statement of the fundamental requirements of electrical engineering education.

In 1919 he was appointed to the Chair of Electrical Engineering in the University of Birmingham and became associated with the South Midland Centre of The Institution, of which he was Chairman in 1922. In his Address he paid a fine tribute to the work of his predecessor, Prof. Kapp, and continued to be prominently connected with the work of the Centre during the whole of his residence in Birmingham. He was responsible for the submission of many papers to The Institution, dealing with the electric discharge and the production of nitric acid, the use of single-core sheathed cables for alternating currents, and many other subjects. He was also responsible for the publication of a considerable amount of research work done under his direction in the university laboratories. He invented, among other things, a single-phase motor, a self-exciting alternator, and a new system of coal-face lighting.

In 1936 he was elected President of Section G of the British Association and delivered a presidential address which dealt with a number of controversial subjects connected with the patent law and with the ethics of the consulting engineer, and defended his profession against the popular criticism of the use made of scientific discoveries for the purpose of war. He stood as a devotee of pure science that had no moral obligations and no ethics, and visualized the power of the engineer to make war impossible, if only he were left undisturbed by the politicians. Quite recently he was appointed chairman of a committee of the Department of Mines, to revise the Regulations for the Use of Electricity in Mining. On several occasions he broadcast accounts of the early pioneers in electrical engineering, and in the Faraday Centenary year he gave the Faraday Lecture of The Institution on the "Birth of Electrical Engineering."

His wife died in 1935, and he leaves two daughters, who were educated as he had always believed that women should be educated, and are graduates respectively of Birmingham and Cambridge.

He will long be remembered as a very successful teacher of electrical engineering. His methods were clear and forceful, and no student could fail to understand the point with which he was dealing. He had an incisive manner and an accuracy of statement which made his lectures of exceptional value. His sudden and unexpected death leaves a gap which it will be difficult to fill, and his memory will long remain among those who were privileged to know him intimately. He was elected an Associate Member of The Institution in 1901, and became a Member in 1908. E. W. M.

MAJOR JOHN POWELL EDWARDS died at Whitstable, Kent, on the 5th March, 1939, at the age of 87. From 1870 to 1879 he served as clerical assistant, first to the late Sir John Gavey and subsequently to the late Sir William Preece, in the Post Office Engineering Department. In March 1879 he entered the telegraph service in South Africa and served as superintendent at Cape Town and subsequently at Fort Beaufort and King William's Town. In 1892 he was promoted to surveyor and district engineer of the Eastern District and 2 years later removed to Cape Town on his appointment as chief engineer and electrician of the Telegraph Department. He was one of the pioneers of the telegraph in South Africa and did great work in the early days when long iron wires on shaky wooden poles had to be maintained under extraordinarily difficult conditions and when it was not unusual for a lineman to ride 100 miles on horseback under most trying conditions to repair breakages and restore vital connections. He retired before the Union of South Africa took place, but 4 years later he came back as a volunteer and worked among the rank and file during the whole period of the Great War. No man was more respected and beloved. He was, indeed, a great little man. He was Major of the Cape Town Highlanders for many years. He was elected an Associate of The Institution in 1878 and a Member in 1901. E. A. S.

ARTHUR ERSKINE died on the 11th January, 1939, at West Didsbury, Manchester, in his 70th year. He joined the General Electric Co. in 1886 as engineer and manager of the company's Peel Works at Salford. Later he was appointed director and works manager of the company's works at Manchester. He resigned in 1905 and entered into partnership with Mr. A. C. Heap to manufacture switchgear and starting gear and supply electrical accessories. In 1913 the firm became a limited company of which he was chairman and managing director until the time of his death. He joined The Institution as an Associate in 1894 and was transferred to full membership in 1900. E. J.

SYDNEY EVERSHED came of a very old family of Sussex yeomen, which can be traced back to the middle ages and has left place names in that county. His father, a man of considerable ingenuity, to which may perhaps be attributed the son's inventive powers, was a tanner at Gomshall in Surrey. In Sydney's early days some misfortune befell the tannery, and the family moved to Wonersh, where Sydney, instead of continuing the normal course of his education, had to help his father in the manufacture of a special tanning oil. In his spare time he interested himself, as a hobby, in the study of atmospheric and other electrical phenomena. Some account of his early experiences will be found in the very interesting reminiscences which he gave to The Institution on the occasion of its Jubilee.*

His first active contact with electrical business seems to have been his engagement with the Hammond Company, a pioneer in the manufacture of electric incandescent lamps, in the early eighties of the last century. When that concern failed he found himself out of employment, and devoted himself for a time at home to the study of methods of electrical measurement. The first measuring instruments designed for industrial use were being developed about that time; and he thought out and made with his own hands a current measurer (usable, of course, as an ammeter or a voltmeter) in which the deflection was produced by the attraction of a fixed on a movable iron.

In 1885 Goolden and Trotter decided to start in London a small factory for the manufacture of the Cardew voltmeter; and Evershed, with his newly made instrument in hand, applied for the post of manager. Successful in his application, he started with half-a-dozen men making electrical instruments in King's Head Court, Westminster—just opposite St. James's Park Station. Moved to Woodfield works, Harrow Road, on the retirement of Trotter and the admission of Ll. B. Atkinson as partner, this business continued (as W. T. Goolden and Co., and later as Easton, Anderson and Goolden) until 1895; in which year Sydney Evershed, in co-operation with E. B. Vignoles whom he had engaged as assistant a few years before, acquired it and continued it under the style of Evershed and Vignoles, Ltd.

Though thus industrially occupied, Evershed never lost his interest in more fundamental research. Over a series of years in the early nineties he carried out, with E. B. Vignoles, an investigation of the magnetic phenomena produced in the cores of transformers; and the results were published in the *Electrician*, then edited by A. P. Trotter. A long research undertaken at a later date led to very interesting papers read to The Institution on the subject of "Permanent Magnets";† and another subject of prolonged investigation was the physical structure of non-conductors, with results also laid before The Institution.‡ For the latter paper he was awarded the Institution Premium.

But though much interested in these more fundamental researches, he applied himself also to the development of his business on industrial lines, and was, as is well known, the originator of a number of successive forms of testing set for the measurement of insulation resistance under pressure. The success of these led to a great expansion of the trade done by his company; and under the trade mark "Megger" his products became known all over the world. Less well-known but equally important work was done in devising instruments for control of various kinds of naval equipment. The helm indicator was produced in 1893 and adopted by the Navy shortly afterwards: and when, about the year 1908, the German

* *Journal I.E.E.* 1922, vol. 60, p. 400.
† *Ibid.*, 1920, vol. 58, p. 780; and 1925, vol. 63, p. 725.
‡ *Ibid.*, 1914, vol. 52, p. 51.

naval menace became acute, instruments were called for, and promptly devised, for the control of guns. These instruments proved of much value in the Great War. By the time that Evershed retired in 1923 from the direct conduct of the business, it had grown to be one of the most important of its kind in the country.

In spite of the difficulties he encountered during the period of his adolescence, Evershed was a man of great culture, and remarkable both as speaker and as writer. Favoured with a retentive memory, he seemed never to forget anything he had once acquired. He became too a good mathematician; and his powers as an exponent of the complicated or abstruse will be in the memory of all who heard him at The Institution. Though he regarded publicity with aversion and avoided as far as he could public functions and large gatherings of all kinds, he was charming when in the company of a few chosen friends, and full of quaint quips and odd humour. His encyclopaedic knowledge and the wide range of his interests made him a most entertaining companion.

He married, in 1904, Margaret, daughter of the late Thomas Ferdinand Walker—well known in connection with the B.S.A. Co., the Walker Ship Log, and other activities in Birmingham—but leaves no children. Far from robust, at any time, he lived to old age without serious illness; and died, in full vigour, on the 18th September, 1939, a couple of days after passing his 82nd birthday. Elected an Associate of The Institution in 1886, he became an Associate Member in 1899, and a Member in 1903. He served on the Council in 1889–90, 1898–1901, and 1906–9, and as Vice-President in 1924–25.

E. B. V.

WILLIAM FRISBY was born in 1873 and died on the 2nd May, 1939. He received his general education at Westbourne School, London, and his technical education at the Regent Street Polytechnic, the Chelsea Polytechnic, and the Manchester Technical School. He served his apprenticeship from 1889 to 1894 with Messrs. W. T. Goolden and Co., London. In the latter year he was apppointed switchboard attendant in the Brighton Corporation Electricity Department, and was subsequently electrician-in-charge in the Hull Corporation Electricity Department, chief assistant engineer at Stockport, and chief assistant at Colchester. In July, 1910, he became borough electrical engineer at Colchester, succeeding Mr. A. R. Sillar, and retained that position until his retirement in 1936 after 34 years' service with the Corporation. He was elected an Associate Member of The Institution in 1904 and a Member in 1916.

ARTHUR FREDERIC HARMER was born on the 15th December, 1878, and died on the 11th January, 1939. He was educated at the City of London School and received his technical education at Battersea Polytechnic. After a short time with Messrs. J. G. Statter and Co., he was appointed electrical superintendent in 1895 by G. Straus and Co. and had charge of all their technical work. From 1900 to 1901 he was employed by the Islington Vestry Electrical Department, first as meter superintendent and subsequently on shift work. In 1901 he was appointed chief technical assistant to the Metropolitan Electric Supply Co., and during his 30 years' service with the company he passed through nearly all their departments. In February, 1931, he became assistant to Mr. F. W. Purse, chief engineer of the London and Home Counties Joint Electricity Authority, resigning a few months later on his appointment in September, 1931, as deputy electrical engineer to the Hammersmith Borough Council. He was promoted to chief electrical engineer in September, 1933, and one of his first jobs was the changing over of the supply pressure from 110 volts to 230 volts. Among his inventions were an e.h.t. switch-fuse and a ring-main controller for e.h.t. distribution gear. He joined The Institution as an Associate Member in 1911 and was elected a Member in 1932. He served on the Council from 1922 to 1925, and was also for many years a member of the Informal Meetings Committee.

F. P.

RAYMOND ARTHUR HARRISON-WATSON, who died at Birkenhead on the 19th July, 1939, was born in London and received his early electrical training with Messrs. Patterson and Cooper, the makers of the Phoenix dynamo, at Dalston. He moved to Paisley in 1897, when the business was transferred from London.

At Paisley he was a colleague of Mr. S. A. MacLeish who, in 1901, with the late Mr. John Hunter, founded the firm of John Hunter and Co., of Liverpool, and when, a few years later, Mr. Hunter was compelled for health reasons to reside permanently in Australia, Mr. Harrison-Watson joined Mr. MacLeish in a partnership which was maintained up to his death.

From its early years, the firm of John Hunter and Co. was closely associated with the medical profession and was responsible for many pioneer developments in electro-medical applications and for the water-cooled Finsen lamp. As one of the leading electrical contracting firms in the North of England it carried out installations in many important public buildings in all parts of the country, including the Lady Chapel and the first half of Liverpool Cathedral, the building of which has been proceeding continuously for nearly 30 years, and also the India Buildings at Liverpool. Mr. Harrison-Watson was an active member of the Electrical Contractors' Association, being Hon. Secretary and Treasurer of the Liverpool branch in 1922–23 and Vice-President of the Association in 1934–35. He was elected an Associate Member of The Institution in 1912 and a Member in 1926, and served on the Committee of the Mersey and North Wales (Liverpool) Centre in 1923–26, 1930–33, and 1938–39. W. P.

HAROLD FIRTH HAWORTH, Ph.D., M.Sc., B.Eng., died on the 18th June, 1939, at the age of 56. He was educated at Liverpool and Zurich universities, and held appointments on the staffs of the City and Guilds College in London and the Imperial College of Science and Technology, South Kensington. During the Great War he served as a Captain in the Royal Engineers, partly in France and partly at Shoeburyness, where he specialized in anti-aircraft activities and helped to develop the searchlight as a weapon of war. He joined Leyland Motors, Ltd., in 1920 as resident principal of Wellington House, the company's hostel for engineer apprentices. At Leyland his versatility, coupled with his vast store of technical knowledge, brought him a

variety of work, and from 1929 to 1933 he held the position of chief engineer. At the time of his death he was, in addition to other work, supervising the design and sales of both trolleybuses and railcars. On various occasions he visited, on behalf of the company, North America, South America, and a number of the European countries, and some of the company's success in these fields is undoubtedly to be attributed to him. Hand-in-hand with his personal reticence went a rare forbearance and kindness, which he attempted to disguise with a brusque manner which deceived no one. He was elected an Associate Member of The Institution in 1908, and a Member in 1920.

THOMAS HESKETH, who died at Lytham St. Annes, Lancashire, on the 13th March, 1939, was born on the 19th April, 1873. His early training was with Messrs. J. H. Holmes, Ltd., and Messrs C. A. Parsons and Co. After this he continued training at Blackpool under his brother, the late John Hesketh, who afterwards became electrical adviser to the Commonwealth of Australia. From Blackpool he went to Madrid with the late Robert Hammond, and assisted in the erection, and afterwards the running, of that station. Returning to England, he was at the Hampstead station for a short time. In 1897 he went to Folkestone and superintended the erection of the generating station, and afterwards became managing engineer of the Folkestone undertaking. Later he was appointed to a seat on the Board. He resigned his position as managing director in 1934, retaining his seat, however, on the Board of the company until his death. He was elected an Associate of The Institution in 1898, an Associate Member in 1899, and a Member in 1903.

A. G. M.

SYDNEY HOLMWOOD HOLDEN died on the 29th May, 1939, at the age of 75 years. He was educated at the Edgbaston Preparatory School and later at King Edward's Grammar School, Birmingham. He then took a short course with Messrs. Hunt and Mitten, engineers, followed by five years on research work with Dr. Gore of Birmingham. Following this, he spent 2 years with a firm of patent agents, after which he joined Messrs. Chamberlain and Hookham in 1888, with which firm he remained to the end of his business career. For many years he was associated with Mr. George Hookham in the development of direct-current mercury-motor meters, and he also devoted much time to an attempt to produce an electrolytic meter. His efforts met with a certain amount of success, but the Great War intervened and delayed the exploitation of his invention. After the war, electrolytic meters did not meet with much favour and his ideas, although possessing considerable technical merit, had to be abandoned. About this time he ceased to take an active part in meter-development work and his activities were confined to the commercial side. He retired from active service in 1929, after 41 years with the company. He joined The Institution in 1902 as a Member and served for many years on the Committees of the Birmingham Local Section and the South Midland Centre, being Chairman of the latter in 1928–29. He took a great interest in standardization and was a member of the B.S.I. Committee dealing with the drafting and revision of the British Standard Specification for Electricity Meters.

S. J.

PROFESSOR ARTHUR EDWARD KENNELLY, D.Sc., was born near Bombay, India, on the 17th December, 1861. He received his early education in private schools in England, Scotland, France, and Belgium, and his first position was on the Staff of the Society of Telegraph Engineers, now The Institution of Electrical Engineers. He joined the Eastern Telegraph Co. in 1876 and was promoted steadily until, in 1886, he became senior electrician on submarine cables, a position which made heavy demands on the technical knowledge and resourcefulness of the holder. This period of his career started him in the direction which formed the basis of his future work in the field of telephony. In 1887 he became associated with Edison and was his principal electrical assistant until 1894. Those years in a hard and intensely practical school were most stimulating to a young engineer. In 1893 he became, in addition, consulting electrician of the Edison Electrical Co., now the General Electric Co. of Schenectady. In 1902 he was appointed Professor of Electrical Engineering at Harvard University and continued in that position until he retired from active service in 1930. From 1913 until 1924 he was Professor of Electrical Engineering at the Massachusetts Institute of Technology, and for some years was Director of Electrical Engineering Research and Chairman of the Faculty of that Institute.

He was actively associated with The Institution of Electrical Engineers, of which he was elected a Student in 1876, an Associate in 1884, a Member in 1894, and an Honorary Member in 1918. He came over to England on many occasions to give lectures on special subjects, and was well known to electrical engineers in this country, both on account of his numerous publications and for the courses of lectures that he came to deliver in England. His book on the use of hyperbolic functions in electrical engineering is a standard work on the subject. One of his outstanding achievements was the suggestion, at the same time as Heaviside, that the transmission of wireless signals across the Atlantic was due to the presence of a reflecting layer in the upper region of the atmosphere, which has been given the name of the Heaviside–Kennelly layer.

Dr. Kennelly found time and energy to engage in many outside activities. He served two terms as President of the American Institute of Electrical Engineers from 1898 to 1900, and was President of the Illuminating Engineering Society during the early days of that organization. He was President of the Institute of Radio Engineers, of the Metric Association, and of the Union Radio Scientifique Internationale, and was Honorary Secretary of the U.S. Committee of the International Electrotechnical Commission.

In the international field his services have been of unusual distinction. He was the U.S. delegate of the Electrical Congresses of 1900 and 1904, when he carried out the onerous duties of General Secretary, and again in 1932, also at the International Radio Conference in Paris in 1921 and in Washington in 1927, where international allocations of radio-transmission frequencies were made. He was a member of the International

Committee of Weights and Measures and attended the last meeting at Sèvres in 1933. In 1921–22 he represented seven co-operating American universities as first Exchange Professor in Engineering and Applied Science at several French universities.

He published several books and was the author of more than 350 papers presented before scientific organizations at home and abroad. He gave his time to committee work without stint, and neither desired nor received any personal credit for it. At the time of his death he was chairman of the Committee of Electrical Definitions, which has already accomplished some important work. His most recent work was the effort that he made towards the establishment of the practical M.K.S. system of units, and he tried hard to get an agreement which would include the mechanical as well as the electrical units. In conference and committee work he was always anxious to get something done and something agreed to. He never attempted to force his own views on his colleagues. He saw his adversaries' point of view as well as his own and was always fair, judicial, and tolerant.

In addition to being an Honorary Member of The Institution, he was also an Honorary Member of the American Institute of Electrical Engineers, of the Société Français des Électriciens, of the Elektrotechnischer Verein, and of the Institute of Electrical Engineers of Japan. He was a member of the American National Academy of Science, of the American Philosophical Society, and of the American Physical Society, and was a Fellow of the American Academy of Arts and Sciences. In 1933 he received the Edison Medal of the American Institute of Electrical Engineers, and was also awarded the Volta Medal in 1927 and a gold medal of the Institute of Radio Engineers in 1932. The French Government conferred upon him the Cross of the Legion of Honour.

To those who knew him personally, he was always a kindly and generous friend and his name will long be remembered by all electrical engineers, both in Europe and in America.

E. W. M.

MAJOR REGINALD WILLIAM KLITZ, who was born on the 13th October, 1880, and died on the 19th September, 1939, obtained his practical training with the Westminster Engineering Co., at the same time attending classes at the Chelsea Polytechnic. From 1900 to 1904 he was employed by the London Electric Supply Corporation in connection with their mains and substations. In the latter year he was appointed mains engineer at Wimbledon, being promoted to chief assistant engineer in December, 1912. During, and for 3 years subsequent to, the Great War he served in the Royal Army Ordnance Department, and finally as Inspector of Ordnance Machinery. In December, 1923, he was appointed sales manager by the North Wales Power Co. and negotiated contracts for bulk and power supplies, and wayleaves, at the same time carrying on some private consulting work. He resigned his appointment in 1931.

He joined the Electricity Board for Northern Ireland in January, 1932, as sales engineer before tariffs, conditions of supply, and facilities for hiring had been determined, and his wide experience was invaluable in deciding these factors which have so much contributed to the success of the undertaking. His power-station experience with the earlier reciprocating engines and the later steam turbines stood him in good stead in negotiating large power supplies where the economics of private plant and public supply were the deciding factors. He was convinced, from experience, of the advantages to be gained by the use of public supply at the equitable tariffs which can now be offered and was an out-and-out enthusiast for electrical development generally. His association of some 5½ years with the electrical industry in Northern Ireland gave to development an impetus commensurate with his unusual ability and enthusiasm.

He was elected an Associate Member of The Institution in 1912 and a Member in 1929, and served on the Committee of the Northern Ireland Sub-Centre in 1936–37.

T. G. C.

ROBERT CARR LANPHIER, Sen., Ph.B., the President of the Sangamo Electric Co., Springfield, Illinois, U.S.A., died on the 29th January, 1939. The electrical industry, not only in America but throughout the world, suffered a severe loss by his death, and a great many people on both sides of the Atlantic are mourning the passing of a very dear friend.

After graduating from Yale University in 1897 with high honour in electrical engineering, he became, as a result of a conversation with the late Mr. Jacob Bunn, interested in electricity meters, and in consequence of the collaboration of these two engineers the Sangamo Electric Co. was started on the 11th January, 1899. The story is told in fascinating detail in a booklet published privately by Mr. Lanphier about 2 years ago, entitled "Forty Years of Sangamo." In 1917, operations were commenced in Toronto, and in 1920 in England, and the success of the three Sangamo concerns in America, Canada, and England, are a monument to his rare ability and kindly nature. He was elected a Member of The Institution in 1931.

Although meters were his speciality, he was for many years recognized as one of the foremost of America's electrical engineers, and his counsel was often sought by research experts in electrical matters. But quite apart from his technical capabilities he will always be remembered with deep feelings of love and respect by his employees in every grade. No one ever approached "R. C.," as he was affectionately known (or Rob by his older friends), without being sure of a sympathetic hearing and a helping hand, and although this naturally applied perhaps more to Springfield than to Toronto and Enfield, those who were fortunate enough to come under his personal eye during his many and always welcome visits shared this regard in the fullest measure.

In spite of his extremely busy business life he found time to take an active part in many public welfare organizations and in the civic life of his home town generally, and this phase of his activity has twice been recognized—one of Springfield's city parks and the new High School in that town have been named after him.

Thus, then, at the comparatively early age of 61, passed from amongst us a true gentleman. "Well done, thou good and faithful servant."

E. H. M.

F. MACKENZIE LEA, who died on the 10th July, 1939, at the age of 63, was a son of the late Mr. Henry Lea, who started the firm of Henry Lea and Son, consulting engineers. He was educated at Bromsgrove School, and entered his father's business after gaining practical experience on outside contracts, both in England and abroad. The activities of the firm are principally in connection with lighting, heating, ventilating, and water engineering. He had very wide experience in these lines and practised as a consultant for about 40 years in Birmingham, having lived there all his life. Among the contracts for which he was responsible were those for the Queen Elizabeth Hospital (Birmingham), the Royal Naval School (Ipswich), the Victoria Law Courts (Birmingham), Birmingham Corporation, and many other public bodies in various parts of the country. At the time of his death he was senior partner of the firm. Throughout his life he had always been very keen on every kind of sport, and was particularly interested in yachting, having for many years organized the Annual Regatta at Abersoch, North Wales. He was elected an Associate Member of The Institution in 1901 and a Member in 1907.

H. H.

CHARLES WILLIAM GODSON LITTLE was born in 1866 at Heckington, Lincolnshire, and was educated at Reigate Grammar School and Finsbury Technical College. In 1889 he obtained an appointment with the Thomson-Houston International Electric Co. of Boston, U.S.A., and was transferred 2 years later to the French Thomson-Houston Co. in their Paris office. He was responsible for the development of Thomson-Houston meters and arc-lighting machines in France and was concerned in the early manufacture of arc lighters in this country at the Maxim Nordenfelt Works, Erith. In 1893 he joined the British Thomson-Houston Co., and was responsible for the construction and equipment of the Ballsbridge power station and the Dublin–Dalkey line of the Dublin Southern Tramways, which was claimed to be the first instance in Great Britain of 3-phase e.h.t. transmission with convertor substations, a number of similar installations being subsequently equipped while he was head of the construction department of the company. In 1899 he was appointed chief executive electrical engineer of the British Electric Traction Co., and was closely connected with the various lighting, power, and traction undertakings of that company, both at home and abroad. He visited New Zealand, India, Argentina, Brazil, and Russia in connection with the inauguration of the Auckland Electric Tramways, the Bombay Electric Supply and Tramways Co., the Rio Grandense Electric Light and Power Undertaking, and the development of a hydro-electric power supply to Leningrad. He was also closely connected with the construction of the Stourport and other power stations of the Shropshire, Worcestershire, and Staffordshire Electric Power Co., and the electrification of the Swansea and Mumbles Railway. He retired from the British Electrical Federation in 1930 and died on the 10th September, 1939. He joined The Institution as an Associate in 1894 and was elected a Member in 1907.

C. E. V.

FRANCIS MADDISON LONG was born in 1867 and died on the 21st June, 1939. Educated at Westminster School and by private tuition, he studied electrical engineering at King's College, London, and from 1887 to 1889 was articled as a pupil to Prof. H. Robinson, consulting engineer, of Westminster. He was subsequently employed by Prof. Robinson as an assistant engineer on the preparation of plans for civil engineering works and for the St. Pancras electric lighting scheme. In 1892 he became resident engineer in connection with the erection of the Duke Street station and the laying of mains for the Norwich Electricity Co. On the completion of the work he was appointed engineer and manager to the company, and when in 1903 the Corporation took over the undertaking he became the city electrical engineer. He retired from this position in 1932, and subsequently became a director of the Westmorland and District Electricity Supply Co. While at Norwich he took particular interest in the development of electricity supply in rural areas. He also introduced in this country the two-part tariff in which there is a fixed charge based on the assessment and a low charge per unit consumed. He was elected an Associate Member of The Institution in 1904 and a Member in 1913. In 1917 he served as President of the Incorporated Municipal Electrical Association.

JAMES ROBERTS PERCY LUNN was educated at King James's Grammar School, Almondbury, and the Technical College, Huddersfield. After 4 years' practical training with local firms of mechanical and electrical engineers he obtained, in 1892, an appointment in the Huddersfield Corporation Electricity Department as a draughtsman in connection with the Corporation's electric lighting scheme. When the electricity works commenced running he became engineer-in-charge, and in 1896 mains superintendent and chief assistant. In 1900 he was appointed borough electrical engineer at Darlington and inaugurated the town's first electricity supply in December of that year. When the town's tramways were electrified in 1903 he also became general manager of the Tramways Department, and in 1926 supervised the change-over to trolleybuses. For many years the costs of generation at Darlington were among the lowest in the country. He was particularly interested in the question of tariffs and introduced an easy-payment box and a seasonal system of charging. He retired in August, 1937, owing to ill-health, and died on the 5th September, 1939.

He was one of the founder members of the Tees-Side Sub-Centre and up to the time of his death was an active supporter of its activities. He served on the Committee for many years and was its Chairman for the 1919–20 Session. Quiet and unassuming in manner, he was always ready to encourage the younger members, and his passing is a severe loss to the Sub-Centre. He joined The Institution as an Associate Member in 1900, and was elected a Member in 1905.

E. E.

GERALD MAXFIELD MADDOCK was born on the 13th September, 1878, and was educated at Liverpool College. He joined the National Telephone Co. at Liverpool in 1894, and was employed on switchboard fitting

and maintenance work, first as a fitter and later as an inspector. At this period he attended evening classes in electrical engineering at Birkenhead Technical School. In 1905 he was transferred to the office of the Engineer-in-Chief in London, where he was engaged on costing and latterly on the preparation of an inventory of the company's plant. He became an assistant engineer in the office of the Engineer-in-Chief to the Post Office in January, 1912, and remained attached to that office until his retirement in 1939, being promoted to executive engineer in 1924 and to assistant staff engineer in 1931. During the earlier years of his service he was engaged in the preparation of specifications for central-battery and automatic exchanges, and from 1933 onwards he was in control of a section of the branch dealing with subscribers' apparatus and miscellaneous services. Two months before his death, which took place on the 16th June, 1939, he had joined the technical staff of the Power Equipment Co. He was elected an Associate Member of The Institution in 1921 and a Member in 1939. A. S. A.

JAMES ARTHUR MORTON died on the 28th November, 1938. He received his general education at the Manchester Central Higher Grade School and began his engineering studies at the Manchester Corporation Technical School. After serving his apprenticeship with Messrs. Richardson and Herbert he entered the firm of Maunsell, Mercier and Co. and in 1897 joined the contract staff of W. T. Glover and Co. In 1900 he obtained a position in the Designing and Estimating Department of the British Insulated and Helsby Cables Ltd. (then the British Insulated Wire Co.), and in 1928 was appointed superintendent of the Estimating Department, which office he held until his death.

He was a combination of scientist, artist, and scholar, and all those with whom he came in contact could not help being impressed by his mental energy, ability, and wide interests, resulting from his prolific reading and literary appreciation. His sound advice on engineering matters was highly valued by those who knew him.

He was elected a Member of The Institution in 1920.

H. R. S. P.

REGINALD PERCY NASH died on the 3rd July, 1939, at the age of 63. He was educated at Barnet Grammar School and Tollington Park College, London. From 1892 to 1894 he attended a day course at the City and Guilds Technical College, Finsbury, and received the College certificate at the conclusion of the course. He then accepted the position of chief testing engineer to the British Insulated Wire Co., Prescot (now British Insulated Cables, Ltd.), and was engaged in the testing of cables during manufacture and on completion, and also conducted experiments on insulating materials. In 1896 he became engineer in charge of the company's cable-laying contracts. From 1897 to 1899 he acted as assistant contract manager. He held this position until 1902, when he was appointed resident electrical engineer to the company (then British Insulated and Helsby Cables, Ltd.), and engineer for the Prescot and District Electric Supply Co., retaining this position when the latter company was taken over by Liverpool Corporation. In 1900 he was granted a Commission in the 2nd V.B. South Lancashire Regiment (which later became the 1/5th Battalion South Lancashire Regiment), a Company of which was initiated and maintained by the B.I. He was later promoted Captain and served in France during the Great War, being demobilized in 1919 with the rank of Major.

He was elected a Member of The Institution in 1922.

B. W.

JOHN HAROLD ODAM died suddenly in Nairobi on the 17th January, 1939, at the age of 50. He was educated at the City and Guilds Technical College under Prof. Silvanus P. Thompson. He then served a varied apprenticeship for 4 years with the British Westinghouse Co., the Lancashire Dynamo and Motor Co., and the British Thomson-Houston Co., leaving the latter firm in 1910 to join the Brush Electrical Engineering Co. as a junior designer in the motor department.

In 1911 he was appointed assistant maintenance superintendent to the Victoria Falls and Transvaal Power Co., and during the years 1914-15 was in charge of switchgear and transformer installations in connection with large power-station extensions. During the early years of the Great War he was in charge of the reconstruction for the production of acetone of the Ardgowan Distillery, Greenock, under the Ministry of Munitions, and from 1917–19 served in Mesopotamia as a commissioned officer in the Royal Engineers, continuing in that country on demobilization with the Iraq Civil Administration, as assistant port engineer on the reconstruction of the Port of Basra until 1921.

In the latter year he joined the Metropolitan-Vickers Electrical Co. as special representative in the Newcastle area, where he acted as liaison officer between his principals and Messrs. Merz and McLellan, which firm he joined in 1923 as superintending engineer on the Natal main-line electrification, being responsible for the erection and working of transformer substations and automatic convertor plant.

From 1924 to 1927 he was also in the service of the South African Railways and Harbours Administration as distribution engineer responsible for the administration and maintenance of the 88-kV transmission system and all substation plant until the plant was handed over to the South African Electricity Commission in 1927, when the electrified section of 173 miles was in full operation.

During this period he also advised the Electricity Commissioners in connection with bulk supplies to various municipalities. In 1927 he returned to England and assisted Messrs. Merz and McLellan in the preparation of certain schemes for the Central Electricity Board, but, preferring a colonial life, he accepted in 1928 the post of general manager of the East African Power and Lighting Co., Nairobi, where he remained until his retirement on account of ill health a few months prior to his death. During this period he was responsible for the extension of his company's activities throughout East Africa, not only in Kenya but in the more settled areas of Tanganyika and Uganda.

His wide experience and genial nature made him the the best of colleagues, and his early death cut short a

career which promised further valuable service to the industry whose interests filled not only his working hours but also his brief leisure.

He joined The Institution as an Associate Member in 1922 and was elected a Member in 1926. A. J. D. S.

LIEUTENANT-COLONEL ALEXANDER OGILVIE, O.B.E., B.Sc., T.D., D.L., a native of Monymusk, Aberdeenshire, died very suddenly at Edinburgh on the 28th May, 1939, at the age of 68. A member of a distinguished family, he obtained his early education at Aberdeen Grammar School and Gordon's College, Aberdeen. He continued his studies at Aberdeen University, the Heriot-Watt College, Edinburgh, and Edinburgh University, where he graduated B.Sc. in engineering. He entered upon his business career with Messrs. King, Brown and Co., electrical engineers, Edinburgh. His marked ability was early recognized by his being appointed manager, and on the retirement from the firm in 1894 of the late Mr. Betts Brown, the late Mr. W. F. King assumed him as a partner. With the new partnership the name of the firm was changed to King and Co., and the business was transferred to Leith Electric Works, Leith. Colonel Ogilvie remained an active member of the firm until his death, and to his skill, keen foresight, business acumen, and personality, is due, in no small measure, the reputation which his firm has attained in the electrical engineering industry in Scotland, a reputation which was recognized during the late war by the Admiralty, who commissioned the firm for important work at Rosyth and Leith.

Outside his business activities Colonel Ogilvie devoted his energies to other worthy objects. He was an enthusiastic Volunteer from the year 1888 when he first joined the Forth Division, Royal Engineers, Submarine Miners, of which unit, reorganized in 1908 under the Territorial Army as the City of Edinburgh (Fortress) Royal Engineers, he assumed command in 1912. He retained this command with distinction throughout the whole period of the Great War and was twice mentioned for valuable services.

By his death The Institution has lost from its membership, to which he was admitted in 1920, one whose nobility of character and genial disposition made him respected alike in business and in public life as typically a gentleman. A. S. G.

EVAN PARRY was born in 1865 at Llanberis, Carnarvonshire. After serving some 5 years with Winton and Co., marine engineers, Carnarvon, during which time he obtained in 1888 a Whitworth Exhibition, he proceeded to the Glasgow University in 1890 where he studied under the late Lord Kelvin. During the latter part of his studies at Glasgow he acted as demonstrator in the Physical Laboratory. He obtained in 1892 a B.Sc. of Glasgow in Civil Engineering and Mechanics.

From 1893 to 1895 he acted as assistant engineer and manager to the City of London Electric Lighting Co., and in 1895 he joined the British Thomson-Houston as a designer of electrical machinery, etc.

From 1897 to 1910 he was chief assistant to Dr. H. F. Parshall, consulting engineer, and was engaged in the design and supervision of the electrical equipments of the Central London Railway and of the Dublin, Bristol, London United, Glasgow Corporation, and other tramways. He was also connected, under Dr. Parshall, with the early stages of the Yorkshire Electric Power Co. and of the Lancashire Electric Power Co.

In 1911 he proceeded to New Zealand to take up the appointment of chief electrical engineer to the Public Works Department of the New Zealand Government, and during the succeeding 8 years he was responsible for the development of various hydro-electric undertakings in the North and South Islands.

In 1919 Mr. Parry retired from his appointment in New Zealand to join the English Electric Co. in London as their chief engineer, but in 1924 he resigned in order to become a partner in the firm of Messrs. Preece, Cardew, and Rider, consulting engineers in Westminster. From 1924 until his death Mr. Parry was associated with many electricity supply schemes, principally in the Dominions and Colonies, among which may be mentioned Uhl River Hydro-Electric Works in the Punjab, Watawala Hydro-Electric Works in Ceylon, extensions of power stations in Ceylon, Sydney, Auckland, Wellington, Dunedin, etc. He made numerous visits to Ceylon and to Australia and New Zealand in recent years.

The pioneer work in the development of water power in New Zealand, which has led to the remarkable growth of the electrical branch of the Public Works Department, is a typical instance of Mr. Parry's work not only in electrical but also in civil and in hydraulic engineering.

He had a wide practical experience and considerable mathematical ability and scientific knowledge. He seldom failed to explore any problem from the mathematical as well as the practical side.

Mr. Parry wrote numerous papers and articles in New Zealand journals and in engineering publications in this country upon not only electrical questions but also upon matters relating to water power, etc., such as "Flow of Water through Pipes," "Friction of Fluids," "Design of Reinforced Concrete Chimneys," "Surge Chambers," etc.

His death in December, 1938, at Llandudno was a great loss to his late colleagues and to those long associated with him. Many sincere expressions of regret have been published, especially in New Zealand, where his work and character had been greatly appreciated.

Mr. Parry joined The Institution as an Associate in 1894 and was elected a Member in 1911. He was also a member of The Institution of Civil Engineers and of other technical societies. A. H. P.

LIEUTENANT-COLONEL WILLIAM JOSEPH POLYBLANK, O.B.E., died on the 19th December, 1938, at the age of 64. He was educated by his father, who was a schoolmaster, and by private tutors at Toynbee Hall, London. Between 1890 and 1898 he was apprenticed to Messrs. Nalder Brothers and Co., and during this period was a part-time student of electrical engineering first at the Finsbury Technical College and later at East London Technical College and the Northampton Institute. He was then employed for 2 years by Mr. A. R. Upward in connection with the design and manufacture of experimental electrical and mechanical apparatus. In 1900 he was appointed as testing officer and inspector

under the Engineer-in-Chief to the General Post Office. Resigning this position in 1903, he joined the Magneta Time Co. as general manager and engineer-in-chief. While serving in this capacity he was responsible for the design and erection of extensive electric signalling and timing circuits, both on land and in large ocean liners. In 1915 he joined the Royal Naval Volunteer Reserve as a lieutenant, and took an appointment at the Admiralty as senior officer in charge of all contracts for, and inspection of, wireless and other electrical apparatus for naval aircraft. He was promoted in 1917 to the rank of Lieut.-Commander. Transferred in 1918 to the Air Ministry with the rank of Major (R.A.F.) he assumed control of the wireless and electrical contracts and inspection department, and was commissioned to visit the United States with full responsibility for all the wireless and electrical contracts placed there. In recognition of his services he was promoted to Lieut.-Colonel and received the O.B.E. He remained in the R.A.F. after the conclusion of hostilities, being appointed in 1920 to the post of development officer at the Instrument Design Establishment, Biggin Hill, Kent, subsequently becoming Chief Technical Officer, R.D.C.5. (Research and Development Communications), which post he held until his death. He was elected a Member of The Institution in 1921.

G. F. M.

GEORGE FREDERIC L. PRESTON, C.B.E., was born in 1861, and died on the 9th February, 1939. After receiving a private education he displayed his engineering bent by an early association with the Metropolitan Brush concern. After a spell of military service in South Africa he joined the London and Globe Telephone Co., afterwards taken over by the United Telephone Co. He transferred later to the Northern District Telephone Co. as engineer under the late Mr. C. B. Clay, and was engaged on telephone work on the North-East Coast for 5 years. When the various independent telephone companies were merged with the National Telephone Co. he was transferred to the Midlands and later became superintendent in charge of the Southern Province.

His wide experience of telephone problems was recognized by the Government, and when the Post Office were authorized to establish a competitive telephone service he was appointed as general manager of the London Telephone Service in 1901. When the National Telephone Co. was taken over by the State in 1912 he became the first controller of the combined London system.

The development of the unified system was retarded by the Great War, but the needs of the Government and the enormous development in the Service Departments threw a heavy load on to Mr. Preston and his associates —a load which continued after the war period owing to the leeway which had to be made up in line and exchange construction. He was responsible for the opening of the first toll exchange in 1921. This was the first exchange in the country to give long-distance calls " on demand." In 1920 he was awarded the C.B.E.

He retired in 1923, but at once assumed duties of an advisory nature on behalf of the Port of London Authority and other large organizations until his eyesight began to fail.

He served as a trooper with Lord Methuen's Horse in the Bechuanaland Field Force (1884–85). During the Great War he served as Commandant of the Post Office Volunteer Engineering Corps, and he commanded the 1st Volunteer Battalion, East Surrey Regiment, from 1916 to 1920. He was in earlier years a prominent member of the Thames Rowing Club and stroked the eight at Henley for several years. He was a former captain and president for several years of the Ventnor Golf Club.

He joined The Institution as an Associate in 1887, and was elected a Member in 1891.

M. C. P.

ROBERT EDWARD ROBSON was born on the 2nd January, 1877, and died on the 20th August, 1939. He was educated at the Newcastle Modern School, and obtained his theoretical training in electrical engineering as an evening student at Armstrong College and at Rutherford College, Newcastle. He served his apprenticeship with Messrs. J. and G. Joicey and Co., locomotive and colliery-engine builders, from 1891 to 1893, and with Messrs. J. H. Holmes and Co. from 1893 to 1898. On leaving Messrs. Holmes he began to undertake the installation of electric lighting in private houses, and his interest in the work was such that he decided to set up in business as an electrical contractor, abandoning his original intention of going to sea. With the help of a few friends he founded in 1900 the Newcastle and District Association of Electrical Contractors. In 1903 Mr. A. C. Coleman joined him as a partner in the firm of Robson and Coleman, electrical engineers and contractors. Mr. Robson continued to trade under this name until his death, though the partnership was dissolved in 1911. He served for 25 years as honorary secretary of the Northern Section of the Electrical Contractors' Association, and was president of the Association in 1923–24. Elected an Associate Member of The Institution in 1903, he became a Member in 1923.

L. R. J.

CHARLES IRWIN SHUTTLEWORTH was born on the 5th October, 1879, and died on the 6th December, 1938. He received his early education, from 1884 to 1893, at Lothersdale Board School. In 1894 he went to the Leeds Mechanics Institute and the Yorkshire College, where he took a 4-years' evening course, working during the day as articled apprentice to F. W. Dickinson. From 1898 to 1900 he was an improver with the Barrow-in-Furness Electricity Department, and from 1900 to 1905 he attended evening classes at the Hull Technical College. In 1900 he became charge engineer, and successively substation superintendent and distribution engineer, to the Hull Corporation Electricity Department. In 1928 he was promoted deputy engineer, and in 1938 chief engineer, to the same department.

While distribution engineer he took an active part in developing supervisory and remote control of d.c. converting substations and brought one system to a satisfactory stage of development at Hull, where about 20 d.c. converting substations equipped with motor convertors were all controlled from the main power station and ran quite satisfactorily without any attendance. The d.c. system was run interconnected and a satisfactory

method of getting supply on again in case of interference due to faults was developed, whereby the whole of the motor convertors could be run up simultaneously and by pressing one button all the machine circuit-breakers closed simultaneously. He made some notable contributions to the cheapening of the cost of distribution for rural supplies.

He had a great fund of typical shrewd Yorkshire humour and was a most entertaining and witty after-dinner speaker. He was a loyal colleague and extremely popular with all who worked with him. He was elected an Associate Member of The Institution in 1908, and a Member in 1938. J. N. W.

JULIAN CLEVELAND SMITH was born on the 7th October, 1878, and died at the age of 61. He obtained his early education, from 1885 to 1896, at various schools in New York. From 1896 to 1900 he attended day courses in mechanical and electrical engineering at Sibley College, Cornell University, and later joined the West Manufacturing Co., where he was engaged in designing heavy and electrical machinery. In 1901–3 he acted as assistant engineer in the firm of Wallace C. Johnson, manufacturers of small electric light and power plant, and in 1903 he was in charge of constructional and electrical installation work at Shawinigan Falls, Canada. From then until 1910 he held the position of general superintendent to the Shawinigan Water and Power Co., Montreal, and was in charge of the transmission lines. In January, 1910, he was appointed chief engineer of the company and became a director and, later, president. He was also president of the Montreal Tramways Co. from 1924 until his death. He was elected a Member of The Institution in 1913.

HERBERT THOMAS SULLY died in January, 1939, at the age of 69. He obtained his electrical training at Faraday House, and at the conclusion of the course he joined Messrs. Crompton and Co., who appointed him their West of England and South Wales supervisory engineer. He did a considerable amount of work in that area during the comparatively early nineties. He then set up in Bristol as an electrical contractor, and later as a consulting engineer, in which capacity he was responsible for the introduction of electricity to a large number of public buildings and business premises in Bristol and the surrounding districts. He held the appointment under the Board of Trade of electrical inspector for Bristol from October, 1898, until April, 1938, and, in conjunction with the borough electrical engineer, designed and was responsible for the Corporation of Neath electricity undertaking for approximately the same period. He was one of the founder members of the Bristol Association of Engineers about 40 years ago and remained a member up to his death, having served as president of the Association and also for many years as its honorary treasurer.

An elaborately equipped electrical and chemical laboratory at his private residence at Stoke Bishop took up a large part of his spare time, and in this connection he was particularly interested in X-ray work and the atomic theory. He was an ardent angler and butterfly collector.

He was elected a Student of The Institution in 1887, an Associate in 1890, an Associate Member in 1900, and a Member in 1905. A. J. N.

HENRY JOHN H. TABOR, who died on the 25th February, 1939, at the age of 64, was a native of Ashford, Kent, where he entered the Post Office as a sorting clerk and telegraphist in May, 1889. After 2 years he moved to Dover where, among other interests, he entered on a course of technical study and in 1902 was promoted to a clerkship in the Post Office Engineering Department at Cambridge. In 1904 he was again promoted to the (now obsolete) grade of sub-engineer and was posted to the testing branch of the Engineer-in-Chief's office in London, under the late Mr. H. Hartnell. This branch was responsible for all tests and examination (other than merely visual) both of the raw materials and of the manufactured items purchased by the Post Office Stores Department, and also for the preparation of many of the specifications, and Mr. Tabor brought to this work an enthusiasm which was of great value in the stress of the years following the establishment of the Post Office London telephone system. He remained in the branch for a period of 30 years until, as an assistant engineer, he retired in December, 1934; and he was associated with many important developments in the field of testing and examination arising out of the extraordinary increase in the range, as well as the volume, of Post Office requirements—postal, telegraph, and telephone. He was a man of great physical strength and endurance, and one of the recollections which must persist most clearly in the minds of his colleagues is that when they felt impelled to put on extra clothing for the sake of comfort, he was as likely as not to decide that the moment was appropriate for divesting himself of his jacket. He was elected an Associate Member of The Institution in 1921 and a Member in 1922. J. W. A.

GEORGE HAMILTON THOMSON, electrical engineer and manager to the Neath Rural District Council electricity undertaking, died on the 12th October, 1938. Born in 1875, he was educated at the public school at Haywood, Lanarkshire, and at Daniel Stewart's College, Edinburgh. From 1890 to 1894 he was an apprentice at the engine and boiler works of Messrs. Muir and Houston, Glasgow, subsequently serving for 2 years as an improver on electrical work with Messrs. Armstrong, Newcastle-on-Tyne. He obtained his theoretical training as an electrical engineer by attending evening classes at the Glasgow Technical School and at Durham College, Newcastle. After spending a year at sea as fourth engineer on one of the steamships of the Lamport and Holt line, he returned to Glasgow in 1897 as a shift engineer in the Corporation Electricity Department. While serving in this capacity he continued his studies, attending day laboratory classes in electrical engineering at the Glasgow Technical School. Appointed in February, 1900, as chief assistant electrical engineer at Doncaster, he resigned later in the same year to take up a similar position at Swansea. He remained with the Swansea undertaking until 1908, and from then until his death was electrical engineer and manager at Neath. He was elected a Member of The Institution in 1919.

ROBERT WIDDOWFIELD WEIGHTMAN was born at Wickham, County Durham, in 1867, and died in December, 1938. He joined the Engineering Department of the Post Office in 1886. After some 7 years' service he was selected to proceed to Natal as an assistant engineer in the Natal Government Post Office Engineering Department. During the Boer War he was actively engaged in and around Ladysmith and in other areas maintaining telephone communications for the British Forces during the early part of the war, and was subsequently mentioned in despatches. In due course he rose to be chief engineer to the Natal Government Telegraphs, and when the Union of South Africa was formed in 1912 he was offered the position of chief telegraph engineer to the new Government. Owing, however, to ill-health he decided to take his pension and to retire to England.

At the end of 1912 he joined the staff of Messrs. Preece, Cardew, and Rider, consulting engineers, and was actively engaged until his death in the telegraph, telephone, and radio developments in South Africa and in the various Crown Colonies. He became a partner in the firm in 1924. In recent years he had been closely associated with the very large development of telecommunication services that has taken place in our Colonial Empire and elsewhere; and special mention may be made of the provision of automatic telephone exchanges of the central office and rural types in Ceylon, Malaya, Kenya, Uganda, Palestine, Nigeria, Gold Coast, Iraq, Bahamas, Mauritius, and Jamaica, broadcasting stations in Hong Kong, Palestine, and other Colonies, radio equipments for the airports on the South African air routes from Uganda to Southern Rhodesia, and also on the new air routes to the West African Colonies and to the Far East. He visited Ceylon and Malaya in 1925 to report upon telecommunication questions.

His association with the Dominions and the Colonies and with the British Post Office brought him into contact with all those interested in the modern developments of telecommunication systems. Colonial engineers were in constant touch with him and to many, whether abroad or on a visit to the Home country, he gave every assistance; many would have regarded leave in England as incomplete without talking over with him their successes and their problems, in which he had such a fatherly interest. His courtesy and kindness to all was greatly appreciated. His death was a serious loss to many, and especially to his partners.

In 1916 he read before The Institution a paper on "Colonial Telegraphs and Telephones." He was a member of various Committees of the British Standards Institution dealing with specifications for materials required for telecommunication construction. He was elected a Member of The Institution in 1896. A. H. P.

HENRY WALL WILKINSON died on the 18th January, 1939. He was educated at King's College School and received his technical training in the applied science department of King's College, London. After serving an apprenticeship with Messrs. J. and G. Rennie, marine and general engineers, Blackfriars, London, he went to sea in the service of the National Steamship Co. Later he served as a draughtsman with various engineering firms and was also in business on his own account as an engineer. He then entered the employ of the Eastbourne Electric Light Co. as an assistant, and after a few months' service with the undertaking was made chief engineer and manager in 1889. Resigning this position in 1900, he returned to London and set up in practice as a consulting engineer. During the Great War he was in charge of munition work. Elected an Associate of The Institution in 1892, he became a Member in 1899.

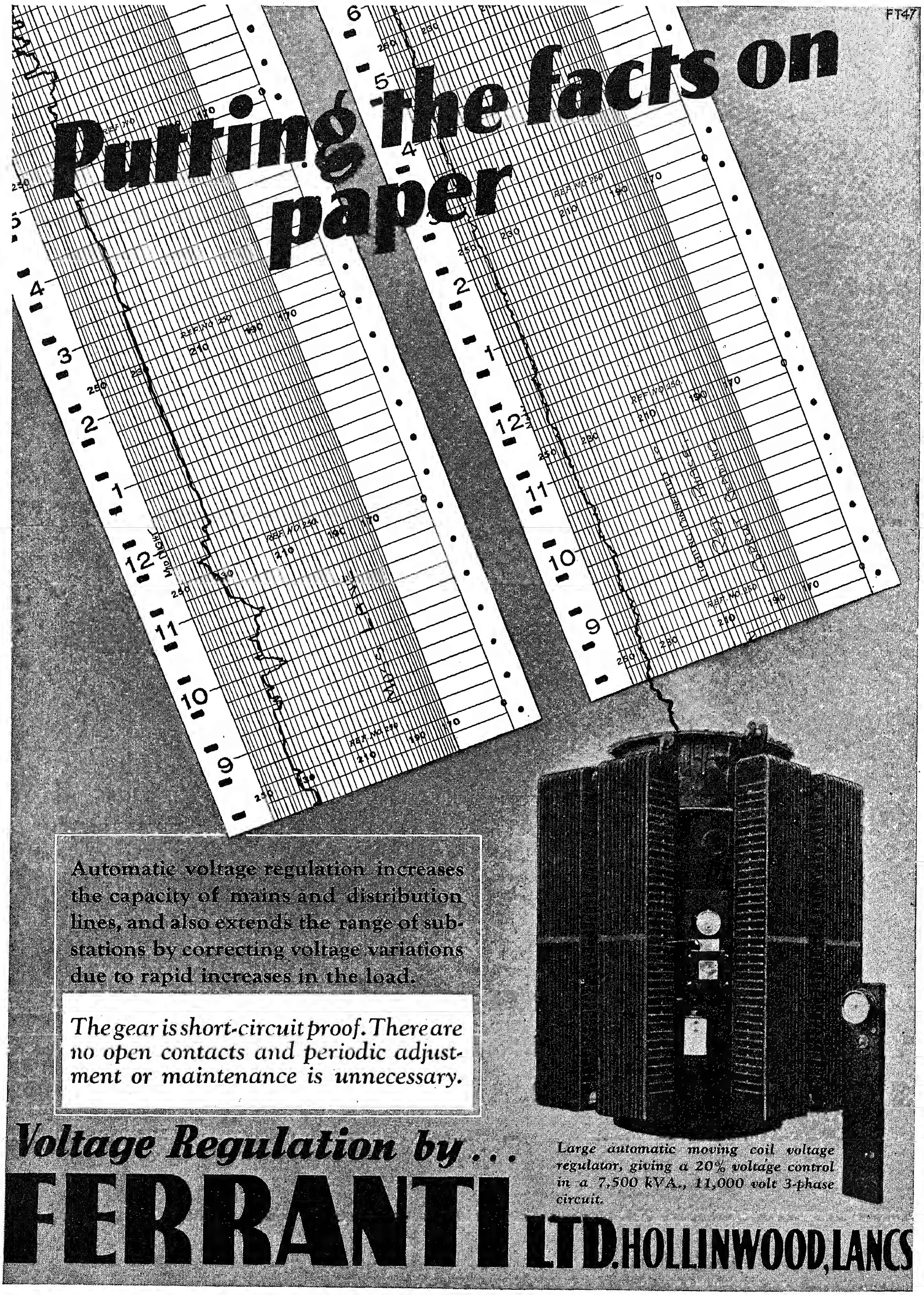
CHARLES JOHN YOUNGS, J.P., was born at Kings Lynn on the 15th April, 1864, and died on the 16th December, 1938. He was educated at private schools, and later augmented his studies at Cambridge University evening classes. His practical training was all obtained in the Post Office Engineering Department. In 1880 he became a telegraphist in the Post Office of his home town and 5 years later transferred to the clerical staff of the Post Office superintending engineer (Eastern District) at Cambridge. From there, 5 years later, he was promoted to chief clerk in the North Wales District office at Liverpool. In December, 1895, he was appointed engineer (2nd class) in charge of the Hull Section of the North-Eastern District, and remained there until 1902 when further promotion took him to the South Wales District where he became engineer (1st class—later designated executive engineer) in charge of the Cardiff Engineering Section. In 1913 he was appointed assistant superintending engineer at the district headquarters in Cardiff.

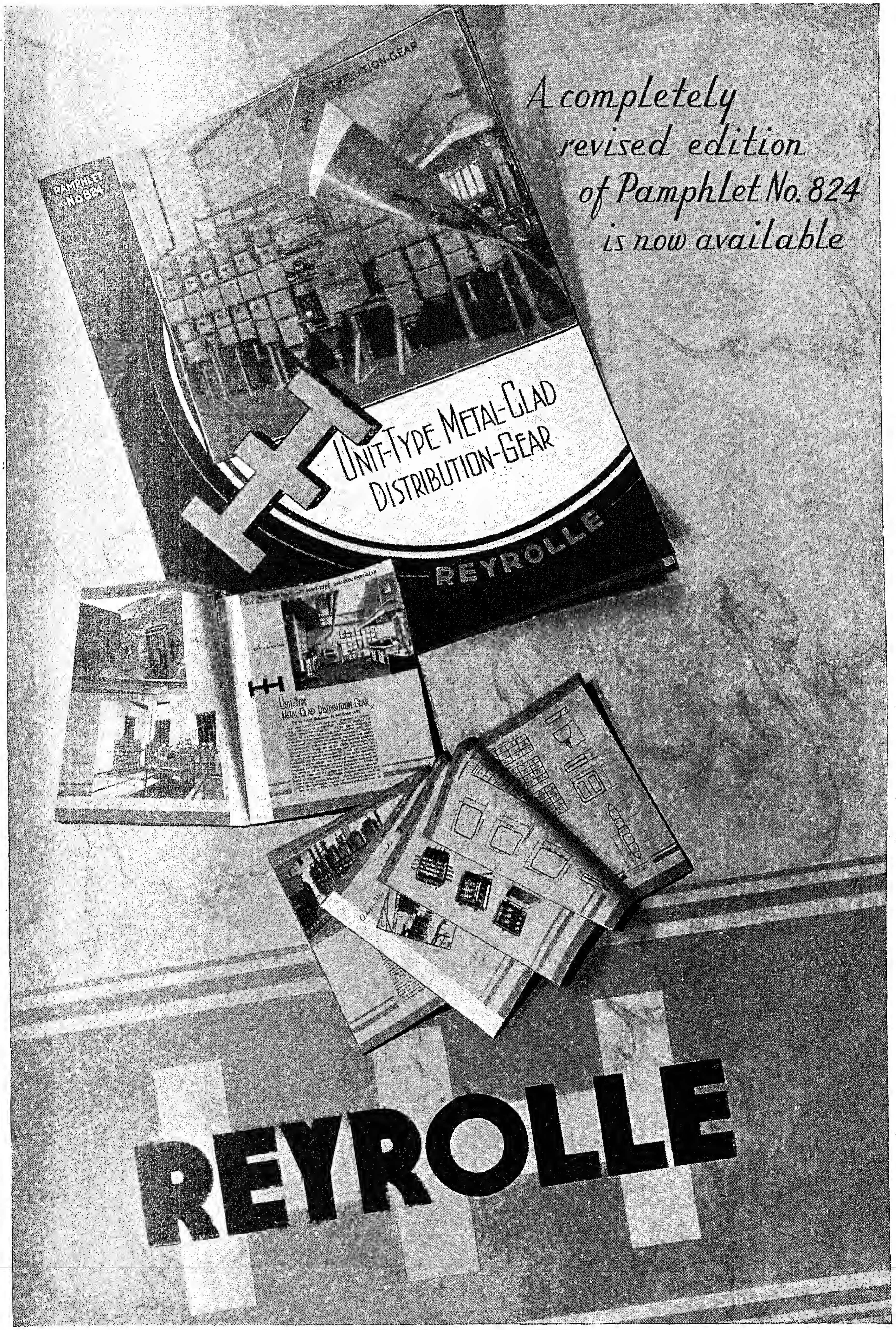
The valuation of the late National Telephone Co.'s plant in the South Wales District prior to the purchase by the Post Office of the whole of the company's undertaking gave him an outlet for his organizing ability, and he was closely engaged upon that exacting work for many months, as well as providing for the actual transfer of all plant and staff to Post Office control in 1912.

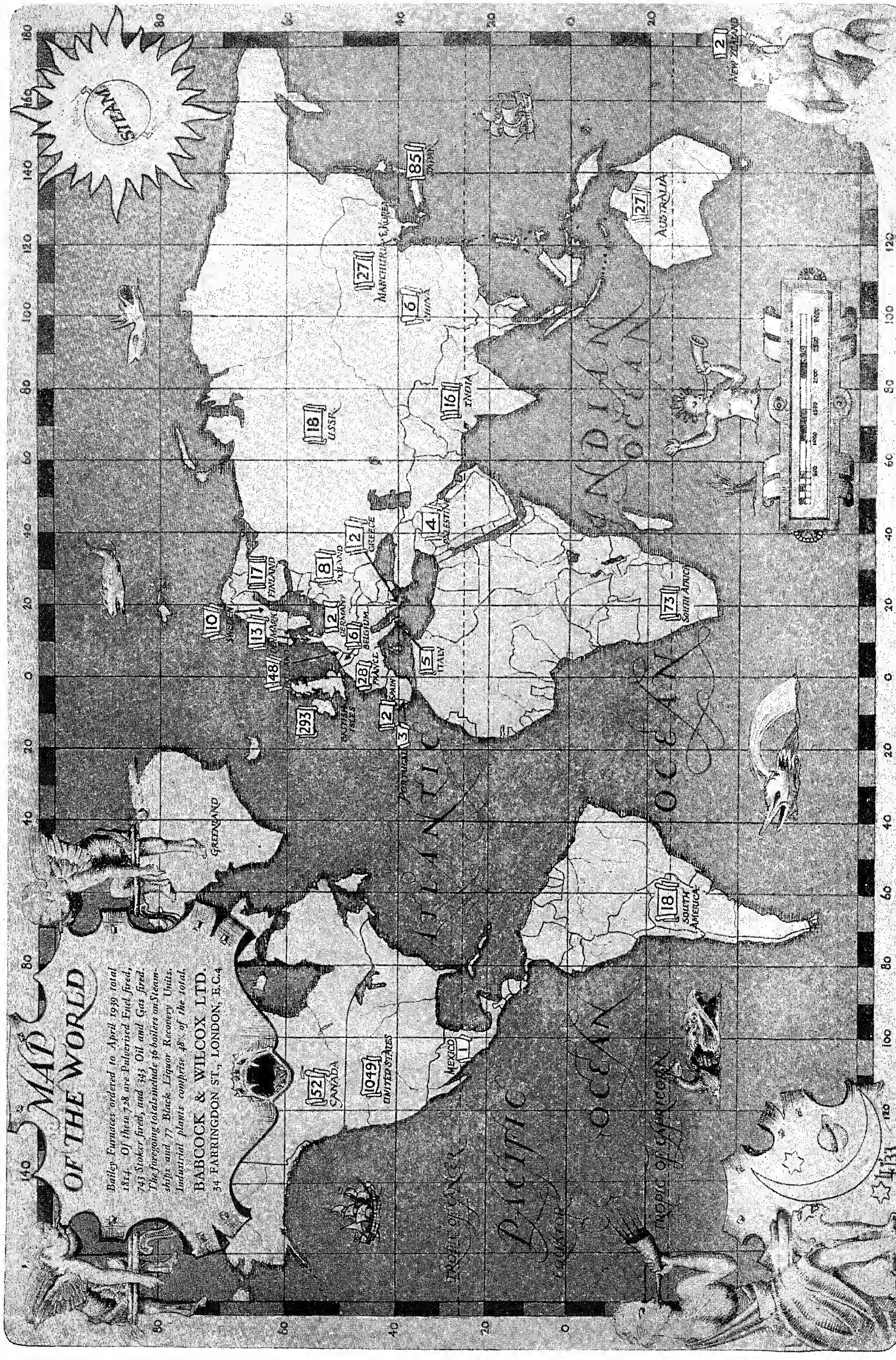
Alert and energetic, he found plenty of work to do in a district embracing all South and West Wales, along the coast to near Aberystwyth, across country to Ludlow, Kidderminster, Worcester, Evesham, Cheltenham, and Gloucester, thence along the north bank of the Severn back to Cardiff. Newport (Mon.) and Hereford, two of the early automatic telephone exchanges, as well as Swansea, a much larger undertaking, were all carried out during his time at Cardiff, not to mention the extensive underground "trunk" cables connecting South Wales with London via the Severn Tunnel and via Gloucester

He retired in April, 1924, on reaching the age of 60, after 44 years' service, and returned to his native Norfolk, where he died on the 16th December, 1938.

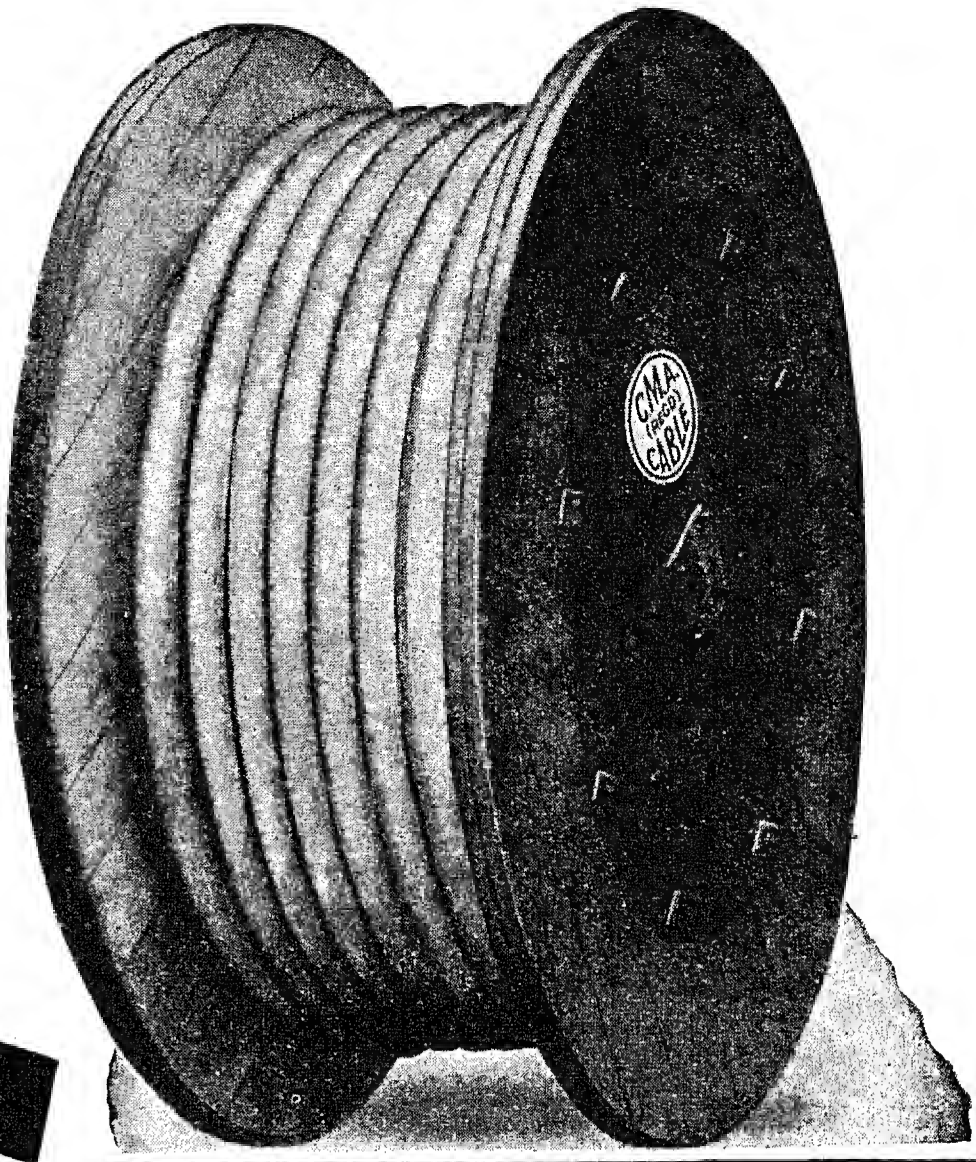
He had taken a deep interest for many years in the Boys' Brigade and served on the Executive Council of that organization for the Welsh region. He was a staunch supporter of Methodism and held strong views on temperance. A fluent and practised public speaker, he was much in demand for meetings with various objects. Even in his retirement he took an active interest in local affairs and did much to secure the extension of electricity to Dersingham and neighbourhood. He was made a Justice of the Peace in recognition of his public services. He was elected a Member of The Institution in 1922. C. C.


FT47
Putting the facts on paper
Automatic voltage regulation increases the capacity of mains and distribution lines, and also extends the range of sub-stations by correcting voltage variations due to rapid increases in the load.
The gear is short-circuit proof. There are no open contacts and periodic adjustment or maintenance is unnecessary.
Voltage Regulation by . . .
Large automatic moving coil voltage regulator, giving a 20% voltage control in a 7,500 kVA., 11,000 volt 3-phase circuit.
FERRANTI LTD. HOLLINWOOD, LANCS


A completely
revised edition
of Pamphlet No. 824
is now available
PAMPHLET No 824
UNIT-TYPE METAL-CLAD
DISTRIBUTION-GEAR
REYROLLE
REYROLLE


MAP OF THE WORLD
Bailey Furnaces ordered to April 1939 total 1814. Of these 728 are Pulverised Fuel fired, 743 Stoker fired, and 343 Oil and Gas fired. The foregoing totals include 36 boilers on Steamships and 77 Black Liquor Recovery Units. Industrial plants comprise 48% of the total.
BABCOCK & WILCOX LTD.
34 FARRINGDON ST., LONDON, E.C.4
STEAM
52 CANADA
1049 UNITED STATES
1 MEXICO
18 SOUTH AMERICA
GREENLAND
293 BRITISH ISLES
48
13 DENMARK
10
17 FINLAND
8 POLAND
2 GERMANY
6 BELGIUM
28 FRANCE
2 SPAIN
3 PORTUGAL
5 ITALY
2 GREECE
4 PALESTINE
73 SOUTH AFRICA
18 U.S.S.R.
16 INDIA
6 CHINA
27 MANCHURIA & KOREA
85 JAPAN
27 AUSTRALIA
2 NEW ZEALAND
PACIFIC OCEAN
ATLANTIC OCEAN
INDIAN OCEAN
TROPIC OF CANCER
TROPIC OF CAPRICORN
EQUATOR

A PERPETUAL SAFEGUARD



MAINS CABLES

TO deal with a firm of repute is a perpetual safeguard — the only guarantee worth having. The reputation of Members of the C.M.A. stands behind their products — this year, next year, always.

MEMBERS OF THE C.M.A.

The Anchor Cable Co. Ltd.
British Insulated Cables Ltd.
Callender's Cable & Construction Co. Ltd.
The Craigpark Electric Cable Co. Ltd.
Crompton Parkinson Ltd. (Derby Cables Ltd.)
The Enfield Cable Works Ltd.
Edison Swan Cables Ltd.
W. T. Glover & Co. Ltd.
Greengate & Irwell Rubber Co. Ltd.
W. T. Henley's Telegraph Works Co. Ltd.
The India Rubber, Gutta-Percha & Telegraph Works Co. Ltd. (The Silvertown Co.)
Johnson & Ph'llips Ltd.
Liverpool Electric Cable Co. Ltd.
The London Electric Wire Co. and Smiths Ltd.
The Macintosh Cable Co. Ltd.
The Metropolitan Electric Cable & Construction Co. Ltd.
Pirelli-General Cable Works Ltd. (General Electric Co. Ltd.)
St. Helens Cable & Rubber Co. Ltd.
Siemens Brothers & Co. Ltd. (Siemens Electric Lamps & Supplies Ltd.)
Standard Telephones & Cables Ltd.
Union Cable Co. Ltd.

CERTIFICATION MARK C.M.A.

Regd. Trade Mark Nos. 566, 585-6-7

C.M.A. CABLES

C.M.A. *Regd Trade Mark Nos. 422219-20-21.*

Advt. of the Cable Makers' Association, High Holborn House, 52-54 High Holborn, London, W.C.1. 'Phone Holborn 7633

I.E.E. PUBLICATIONS

The Journal.
Published monthly, and circulated free of charge to members of all classes. Single Numbers: members of all classes, 5s. 3d.; non-members, 10s. 6d.

Ten-Year Index to the Journal.
To Vols. 1–10 (1872–82), 2s. 6d.; 11–20 (1882–91), 2s. 6d.; 21–30 (1891–1901), 2s. 6d.; 31–47 (1901–1911), 2s. 6d.; 48–59 (1912–21), 2s. 6d.; 60–69 (1922–31), 10s. 6d.

Proceedings of the Wireless Section.
Published two or three times yearly, and circulated free of charge to members of the Wireless Section. Additional Numbers: members of all classes, 2s. 6d.; non-members, 5s.

Students' Quarterly Journal.
Published in March, June, September, and December, and circulated free of charge to Students, and Graduates under the age of 28. Single Numbers: members of all classes, 1s. 6d.; non-members, 2s. 6d. Annual Subscription: members of all classes other than Students, and Graduates under the age of 28, 6s.; non-members, 10s.

Science Abstracts (Section A, Physics; Section B, Electrical Engineering).
Published monthly. Consists of full abstracts from the leading Scientific and Technical Journals of the whole world, thus presenting in a form convenient for immediate reference a complete and concise record of the progress of Electrical Engineering and Physical Science. Single Numbers: members of all classes, 1s. 9d.; non-members, 3s. 6d. Annual Subscription: members of all classes other than Students, and Graduates under the age of 28, one Section 12s. 6d., both Sections 20s.; Students, and Graduates under the age of 28, one Section 5s., both Sections 7s. 6d.; non-members, one Section 35s., both Sections 60s.

The History of The Institution of Electrical Engineers, 1871 to 1931. By Rollo Appleyard.
4to, 342 pp., 38 pl. Price per copy: members, 12s. 6d.; non-members, 18s. 6d.

History and Objects of The Institution.
Supplied free to members and non-members.

Catalogue of the Lending Library.
Revised 1936. Supplied free to members.

Regulations for the Electrical Equipment of Buildings.
Eleventh edition, June 1939. Cloth covers, 1s. 6d. (postage 3d.). Paper covers, 1s. (postage 2d.).

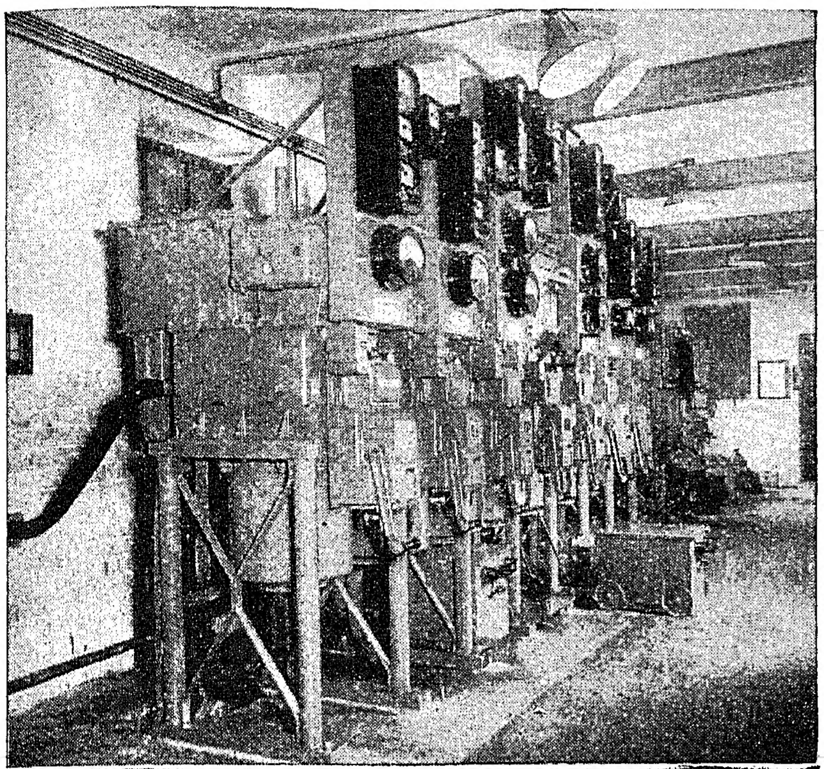
Regulations for the Electrical Equipment of Ships.
Third Edition, September 1939. Cloth covers, 3s. (postage 3d). Paper covers, 2s. (postage 2d.).

Model Forms of General Conditions.
Form A: For Home Contracts (with erection). Revised 1938. 2s. (postage 2d.). *Form B1:* For Export (delivery f.o.b.). Revised December 1928. 1s. *Form B2:* For Export (including complete erection or supervision of erection). Revised December 1928. 1s. *Form C:* For the Sale of Goods other than Cables (Home, without erection). Issued April 1924. 6d. *Form D:* For the Sale of Cables (Home, without erection). Issued April 1924. 6d.

Papers set at the Associate Membership Examination (formerly the Graduateship Examination).
Price 1s. per set.

The above publications can be obtained, post free except where otherwise stated, from the Secretary of the I.E.E. or from Messrs. E. and F. N. Spon, Ltd., 57 Haymarket, S.W.1.

LIST OF ADVERTISERS IN THIS ISSUE



NOTE

ADVERTISEMENT copy and blocks should reach the authorized agents, Industrial Publicity Service, Ltd., 4 Red Lion Court, Fleet Street, E.C. 4 (Telephone: Central 8614), not later than the 16th of each month for publication the following month.

Inquiries regarding space in this section of the *Journal* should be addressed to the Manager.

NORTH-WESTERN CENTRE.

Chairman.—O. Howarth.
Hon. Secretary.—L. H. A. Carr, M.Sc.Tech., "Oakleigh," Cambridge Road, Hale, Altrincham, Cheshire.

SCOTTISH CENTRE.

Chairman.—Prof. S. Parker Smith, D.Sc.
Hon. Secretary.—R. B. Mitchell, 154, West George Street, Glasgow, C.2.
Hon. Assist. Secretary.—H. V. Henniker, 172, Craigleith Road, Edinburgh.

Dundee Sub-Centre.

Chairman.—A. A. B. Martin, B.Sc.
Hon. Secretary.—P. Philip, c/o Electricity Supply Dept., Dudhope Crescent Road, Dundee.

SOUTH MIDLAND CENTRE.

Chairman—H. Joseph.
Acting Hon. Secretary.—H. Hooper, 65, New Street, Birmingham.

East Midland Sub-Centre.

Chairman.—S. J. R. Allwood.
Hon. Secretary.—J. F. Driver, Brighton House, Herrick Road, Loughborough.

WESTERN CENTRE.

Chairman.—T. E. Alger.
Hon. Secretary.—G. L. Coventon, 126, London Road, Gloucester.

Devon and Cornwall Sub-Centre.

Chairman.—E. F. Kill.
Acting Hon. Secretary.—C. J. Hocking, Plymouth Corporation Electricity Dept., Armada Street, Plymouth.

West Wales (Swansea) Sub-Centre.

Chairman.—A. Rees.
Hon. Secretary.—R. Richards, 78, Glanbrydan Avenue, Swansea.

Hampshire Sub-Centre (directly under the Council).
Chairman.—W. S. Lonsdale.
Hon. Secretary.—A. G. Hiscock, c/o City of Portsmouth Electricity Undertaking, 111, High Street, Portsmouth, Hants.

Northern Ireland Sub-Centre (directly under the Council).
Chairman.—J. F. Gillies, Ph.D., B.E., B.Sc.(Eng).
Hon. Secretary.—J. McCandless, M.Sc., Burn Brae, Strangford Avenue, Belfast.

INFORMAL MEETINGS.

Chairman of Committee.—

METER AND INSTRUMENT SECTION.

Chairman.—F. E. J. Ockenden.

TRANSMISSION SECTION.

Chairman.—F. W. Purse.

WIRELESS SECTION.

Chairman.—E. B. Moullin, M.A.

OVERSEAS COMMITTEES.

AUSTRALIA.

New South Wales.

Chairman.—V. L. Molloy.
Hon. Secretary.—

Queensland.

Chairman and Hon. Secretary.—J. S. Just, c/o Box 1067N, G.P.O., Brisbane.

South Australia.

Chairman and Hon. Secretary.—F. W. H. Wheadon, Kelvin Building, North Terrace, Adelaide.

Victoria and Tasmania.

Chairman and Hon. Secretary.—H. R. Harper, 22-32, William Street, Melbourne.

Western Australia.

Chairman.—J. R. W. Gardam.
Hon. Secretary.—A. E. Lambert, B.E., 35, The Esplanade, South Perth.

CEYLON.

Chairman.—Major C. H. Brazel, M.C.
Hon. Secretary.—D. P. Bennett, c/o Messrs. Walker, Sons & Co., Ltd., Colombo.

INDIA.

Bombay.

Chairman.—R. G. Higham.
Hon. Secretary.—A. L. Guilford, B.Sc.Tech., Electric House, Post Fort, Bombay.

Calcutta.

Chairman.—F. T. Homan.
Hon. Secretary.—D. H. P. Henderson, c/o Calcutta Electric Supply Corporation, Post Box 304, Calcutta.

Lahore.

Chairman.—V. F. Critchley.
Acting Hon. Secretary.—Saudagar Singh, M.Sc., Electrical Engineer to Government, Punjab, Lahore.

Madras.

Chairman.—E. J. B. Greenwood.
Hon. Secretary.—W. de Bruyn, District Electrical Engineer, M. & S.M. Railway, Perambur, Madras.

NEW ZEALAND.

Chairman.—F. T. M. Kissel, B.Sc.
Hon. Secretary.—P. H. Mason, P.O. Box 749, Wellington, C.1.

SOUTH AFRICA.

Transvaal.

Chairman and Hon. Secretary.—W. Elsdon-Dew, Box 4563, Johannesburg.

LOCAL HONORARY SECRETARIES ABROAD.

ARGENTINA: R. G. Parrott, Tucuman 117, Buenos Aires.
CANADA: A. B. Cooper, Ferranti Electric Ltd., Mount Dennis, Toronto, 9.
CAPE, NATAL, AND RHODESIA: G. H. Swingler, City Electrical Engineer, Corporation Electricity Dept., Cape Town.
FRANCE: P. M. J. Ailleret, 20, Rue Hamelin, Paris (16e).
HOLLAND: W. Lulofs, D.Ing., Hoogte Kadijk, 200, Amsterdam, C.
INDIA: K. G. Sillar, c/o Calcutta Electric Supply Corporation, Post Box 304, Calcutta.
ITALY: L. Emanueli, Via Fabio Filzi, 21, Milan.
JAPAN: I. Nakahara, No. 40, Ichigaya Tanimachi, Ushigomeku, Tokio.
NEW SOUTH WALES: V. J. F. Brain, B.E., Chief Electrical Engineer, Department of Public Works, Bridge Street, Sydney.
NEW ZEALAND: P. H. Mason, P.O. Box 749, Wellington.
QUEENSLAND: J. S. Just, c/o Box 1067N, G.P.O., Brisbane.
SOUTH AUSTRALIA: F. W. H. Wheadon, Kelvin Building, North Terrace, Adelaide.
TRANSVAAL: W. Elsdon-Dew, Box 4563, Johannesburg.
UNITED STATES OF AMERICA: Gano Dunn, c/o The J. G. White Engineering Corporation, 80, Broad Street, New York, N.Y.
VICTORIA AND TASMANIA: H. R. Harper, 22-32, William Street, Melbourne.
WESTERN AUSTRALIA: Prof. P. H. Fraenkel, B.E., The University of Western Australia, Crawley, Perth.

STUDENTS' SECTIONS.

LONDON.

Chairman.—A. H. Young.
Hon. Secretary.—G. King, B.Sc.(Eng.), 42, Festing Grove, Southsea, Hants.

NORTH-WESTERN.

Chairman.—C. B. Simpson.
Hon. Secretary.—R. M. A. Smith, Meter Engineering Dept., Metropolitan-Vickers Electrical Co., Ltd., Trafford Park, Manchester, 17.

SCOTTISH.

Chairman.—H. C. Stevenson.
Hon. Secretary.—J. S. Tait, 18, Buccleuch Avenue, Clarkston, Glasgow.

NORTH-EASTERN.

Chairman.—A. T. Crawford.
Hon. Secretary.—J. Kemsley, 30, Jesmond Road, Newcastle-on-Tyne.

MERSEY AND NORTH WALES (LIVERPOOL).

Chairman.—R. D. Haigh, M.Eng.
Hon. Secretary.—T. W. Hunt, Laboratories of Applied Electricity, The University, Liverpool, 3.

SOUTH MIDLAND.

Chairman.—H. J. Sheppard, B.Sc.
Hon. Secretary.—B. S. Copson, 88, Reservoir Road, Olton, Birmingham.

NORTH MIDLAND.

Chairman.—F. R. Haigh.
Hon. Secretary.—A. E. Cunningham, 25, Kelcliffe Lane, Restmore Estate, Guiseley, Leeds.

SHEFFIELD.

Chairman.—B. Calvert.
Hon. Secretary.—J. H. H. Teece, c/o Metropolitan-Vickers Electrical Co., Ltd., Howard Gallery, Chapel Walk, Sheffield, 1.

BRISTOL.

Chairman.—H. D. Weeks, B.Sc.(Eng.).
Hon. Secretary.—J. W. Dorrinton, 45, Trelawney Road, Cotham, Bristol, 6.

THE I.E.E. BENEVOLENT FUND.

There are many members and former members of The Institution who are finding life difficult. Please help them by sending a donation to the I.E.E. Benevolent Fund when remitting your subscription to The Institution.

The object of the Fund is: "To afford assistance to necessitous members and former members (of any class) of The Institution of Electrical Engineers who have paid their subscription for at least five years consecutively or compounded therefor, and to the dependants of such members or former members."

Donations should be addressed to

THE HONORARY SECRETARY, THE BENEVOLENT FUND,
THE INSTITUTION OF ELECTRICAL ENGINEERS,
SAVOY PLACE, W.C.2.

LOCAL HON. TREASURERS OF THE FUND.

Irish Centre: J. A. Butler. *North-Eastern Centre:* V. A. H. Clements. *North Midland Centre:* R. M. Longman. *Sheffield Sub-Centre:* W. E. Burnand. *North-Western Centre:* T. E. Herbert. *Mersey and North Wales (Liverpool) Centre:* A. C. Livesey. *Scottish Centre: (Glasgow)* A. Lindsay; *(Edinburgh)* D. S. Munro. *Dundee Sub-Centre:* P. Philip. *South Midland Centre:* H. Hooper. *Western Centre: (Bristol)* E. P. Knill; *(Cardiff)* J. W. Elliott. *Hampshire Sub-Centre:* W. P. Conly, M.Sc.

PRINTED BY UNWIN BROTHERS LIMITED, LONDON AND WOKING